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STUDY OF WINDS, DIFFUSION, AND EXPANSION OF GASES IN THE UPPER ATMOSPHERE

FINAL REPORT

CONTRACT NO. NASw-396

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON 25, D. C.

Rqd 24575

MAY, 1963

GEOPHYSICS CORPORATION OF AMERICA BEDFORD, MASSACHUSETTS

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SECTION 1

INTRODUCTION

Investigations of upper atmospheric parameters utilizing sodium and lithium vapor as a trace element were conducted under Contracts NASw-25 and NAS5-215. These investigations were continued under Contract No. NASw-396. The results of these previous investigations as well as the experimental and analytical methods used are discussed in detail in numerous technical reports prepared under the referenced contracts and presented at meetings and in open publications. Briefly, the method involves use of a rocket-borne vaporizer which ejects a trail of sodium and lithium vapor along the rocket trajectory. Resonance scattering of sunlight causes the trail to be visible and easily photographed during twilight when sky background is low, but the high altitude trail is illuminated. Triangulation techniques are used to measure the motion and growth of the trail. Winds and diffusivity are directly determined from these measurements. Other investigations concern the study of turbulence around 100 km, the expansion of clouds released at altitudes of from 400 to 700 km, and the determination of temperature from the measured width of the resonance line. The temperature determinations were done by Professor J. E. Blamont and associates.

During the period covered by this report, a major effort was directed toward the measurement of winds and the correlation with simultaneous measurements using other techniques. These other methods included rocket grenades, Langmuir probe, Pitot tube, and CW propagation studies. Another major purpose was participation in the coordinated international program to study winds utilizing the sodium vapor method. Launch sites participating in this program were located at Wallops Island, Fort Churchill, Eglin Air Force Base, France, Algeria, Argentina, Australia, and Sardinia. The objectives were to investigate global wind structure by sequential twilight firings from as many of the participating sites as practical due to weather and range facilities.

A total of 13 rockets of the Nike-Asp, Apache, or Cajun types were launched from Wallops Island during this reporting period. The expected wind measurements were obtained in all flights except two Asps which did not reach sufficient altitude due to improper second stage burning. Eight of the flights were accompanied by rocket grenades and arcsondes; three by Langmuir probes; two by Pitot static tubes; and one with CW propagation measurements.

Two sodium payloads were furnished with technical assistance for firing at Eglin Air Force Base. Both of these flights experienced vaporizer malfunction although wind data could be obtained from one of them. Similar difficulties occurred during one of the Wallops firings but good data was obtained. Inclement weather had delayed flights at Churchill and the series was concluded due to uncertain vaporizer performance before any firings occurred there.

SECTION 2

INSTRUMENTATION AND EQUIPMENT

2.1 ROCKET INSTRUMENTATION

All of the rocket payloads were essentially the same as those used previously. Those flown on Asps were constructed with heavier nose cones, skins and coupling rings. A complete description of the entire system including wiring diagrams, photographs, and mechanical drawings is given in the Final Report on Contract No. NAS5-215 dated October, 1962. The vaporizers all contained sodium and some had varying amounts of lithium. In flight, the vaporizers were ignited with an electrically fired squib which was activated by a preset timer. The ignition sequence is completely described in GCA Technical Report "Development and Testing of Ignition System for Rocket-Borne Sodium Vaporizer."

During November-December 1962, three vaporizers malfunctioned in flight. The resulting trails of sodium vapor were of lower than normal density and thus less bright. One of the trails from Eglin was not bright enough to be photographed and no data was obtained. The other Eglin trail and the Wallops trail were photographed and wind measurements were obtained. An investigation to determine the cause of the improper burning was conducted and a special report entitled "Sodium Vaporizer Malfunction" dated 5 March 1963 was prepared. This report should be consulted for details of the investigation. Only a summary of the findings and conclusions will be given here.

The facilities for vaporizer preparation at GCA are limited since they were designed to supply only a relatively few payloads for the NASA sponsored investigations which have constantly required modifications and development of new techniques. The facilities were suited for such services rather than production. During the past year, however, the demand for vaporizers increased greatly. The increase was due in part to an increase in the direct NASA effort but mostly indirectly through requests from Italy, Pakistan, Sandia Corporation, and to the large number of firings associated with Project FISH BOWL. It became apparent that the limited GCA facilities would cause difficulty in delivery schedules unless the facilities were expanded or outside facilities were used. Several chemical companies with proper facilities are available in this area; and even with the relatively small quantities involved, preparation of the chemicals would be cheaper and schedules could be maintained. Gray Laboratories and Chemical of Gloucester, Inc., was selected. A series of test firings proved that the chemicals could be satisfactorily prepared in larger quantities. Commercial blenders were used for drying and mixing of the thermite, and sodium was machine-chopped instead of the laborious hand extrusion method. All operations were conducted under an inert atmosphere of argon and shipped in sealed containers with a positive argon pressure. The vaporizer loading was done at GCA until the fall of 1962, when due to the pressure of shipping schedules, some loading was also done by Gray Chemical. The first group of vaporizers totally prepared by Gray Chemical performed satisfactorily during Project FISH BOWL.

Upon termination of the November-December series, the remaining vaporizers from Wallops Island and Fort Churchill were returned to GCA for the investigation. A fault in the vaporizers was found after removal of the ignition mixture. The thermite sodium mixture normally forms a hard, dense cake after being packed. The faulty vaporizers were softer and flaky. They were also much easier to ignite than a proper mixture as evidenced by the fact that one was accidently ignited while performing a standard operation of removing some of the mixture.

A total of 17 test firings were conducted and several chemical analyses of various mixtures were obtained in order to determine the cause of the faulty burning. From the results of these tests, radar records from Wallops Island, visual observations of the faulty burning, and past experience, it was concluded that the vaporizers burned much too fast and ejected a large portion of their charge in a short time after ignition.

The test series confirmed prior experience that many relative small variations in preparation of chemicals or loading procedure may have a significant influence on the burning rate. However, none of the tests indicated effects which were great enough to explain the failures. The only possible explanation was obtained from a quantitative analysis of the mixture. A large weight deficiency was found in the iron content. If the iron oxide were not properly dried and water accounts for the observed low weight of iron, a rapid burn rate might be expected. This would be expected since the water would destroy a large portion of the sodium and thus lose its cooling effect. Hydroxide coating on the pellets could also reduce the binding effect of the sodium and thus produce the soft, flaky texture of the mixture. However, it has not been possible to substantiate this theory.

The investigation re-affirmed that vaporizers prepared by the specified GCA method consistently perform as required. Three payloads were prepared by this method and fired from Wallops Island during February 1963. All three performed as predicted.

2.2 PHOTOGRAPHIC INSTRUMENTATION

The techniques and equipment used are fully described in the Final Report on Contract No. NASw-25 and NAS5-215 and in GCA Technical Report No. 61-2-N on Contract No. NAS5-215. Standard 70-mm mounts and cameras were used for Wallops firings. Sites were at Dover Air Force Base, Andrews Air Force Base, Camp A. P. Hill, and Dam Neck Naval Training Center. The Wallops Station Photographic Section also operated two or more sites in the vicinity of launch. The cameras used were primarily

K-24's. The close in sites are particularly helpful for observation of the lower trail especially when conditions are cloudy or hazy and attenuation from the distant sites is increased.

The instrumentation for Fort Churchill consisted entirely of modified K-24 cameras which were adapted specially for cold weather operation. Sites were established at Eskimo Point, Seal River, Belcher, Twin Lakes, and at the launch area. Operations at all sites were satisfactory as far as could be determined without an actual firing.

SECTION 3

ROCKET FIRINGS

A summation of rocket firings occurring at Wallops Island is given in Table 1.

The objectives of the winter series of firings were to periodically measure the winds during February in order to investigate the rapid warming phenomena and to correlate the results with measurements made with the grenade technique performed at the same time. The flights were to begin on 6 February; but due to difficulties of scheduling, weather, and winds, the first flight was during the evening of 1 March. This flight was successful and was followed by a successful grenade rocket. This same sequence was successfully repeated on the following morning of 2 March. Just prior to the sodium flight of 2 March, a Cajun rocket was fired which ejected about 50 lbs. of water at 100 km. This event was observed visually and photographically at the camera sites and a brief special report was submitted.

TABLE 1

ROCKET FIRINGS AT WALLOPS ISLAND

Rocket Type	NASA No.	Firing Date	Firing Time EST	Coordinated* Firings at W. I.
Nike Cajun	10.100	1 March 1962	1823	Grenades
Nike Cajun	10.101	2 March 1962	0554	Grenades
Nike Cajun	10.102	23 March 1962	1844	Grenades
Nike Cajun	10.103	27 March 1962	1848	Grenades
Nike Asp	3.20	17 April 1962	0443	Grenades
Nike Asp	3.21	6 June 1962	1956	Grenades Pitot static tube
Nike Asp	3.22	7 June 1962	0352	Second stage failure
Nike Apache	14.13	7 November 1962	0553	Langmuir probe
Nike Apache	14.17	30 November 1962	0615	Langmuir probe Sodium from Algeria and Argentina
Nike Apache	14.18	5 December 1962	1716	Langmuir probe
Nike Asp	3.11	18 February 1963	1814	Second stage failure
Nike Apache	14.35	20 February 1963	1818	Grenades at Wallops Island & Fort Churchill
Nike Apache	14.39	21 February 1963	1816	

*Most firings were also supported by an arcsonde.

Periodic flights of sodium and grenade rockets were continued. Coordinated firings occurred on 23 March, 27 March, 17 April, and 6 June. The 6 June firings also included a rocket carrying a Pitot static tube. Most of the firings were accompanied by an arcsonde.

Firings on 7 November, 30 November, and 5 December were accompanied by Langmuir probe measurements of electron density. The 30 November and 5 December flights were also part of the international series. The 30 November firing followed similar firings from Algeria and Argentina.

The firing of 20 February 1963 was accompanied by successful grenade firings from both Wallops and Fort Churchill. The last three firings also verified vaporizer performance after the difficulties experienced during the fall series.

SECTION 4

WIND DATA

Wind data was obtained from 11 of the 13 flights conducted at Wallops Island during the period covered by this report. Second stage failure occurred during flights of two Asp rockets and thus insufficient altitude was obtained. The winds are given in Figures 1 through 22. Values of speed and direction are shown as a function of altitude on separate plots for each firing. The direction is called "direction of transport vector" which describes the direction of actual trail motion. Dotted lines in the lower portion of some trails indicate that data was obtained from stereo sites and thus only at the points indicated. Other parts of the curves were obtained from so many points with the analog reduction system that curves are essentially continuous.

SECTION 5

ANALYSIS OF WIND DATA

During the period August, 1959 through February, 1963, wind measurements have been obtained during 20 different twilights at Wallops Island. Measurements during two twilights were reported at Sardinia during April, 1961 and three measurements were previously made at Holloman AFB, New Mexico in October, 1955, April 1956 and November 1957. A continuing effort has been made to determine seasonal, diurnal effects and correlation with other phenomena such as solar activity, E-layer variations and wind measurements by other methods. A summary of some of the results of this effort is given here.

5.1 COMPARISON WITH OTHER MEASUREMENTS

It is difficult to compare these measurements with wind data from other methods since no other data above 100 km has been published and most published data below this altitude is either averaged or reported in an analytical form which masks individual measurements. Winds obtained from rocket grenades are generally in agreement with those from the sodium trail taken at the same time. Most of the published data is from observation of meteor trails. Radar observations produce large quantities of data but due to the methods, the results are published after being averaged and contain large height uncertainty. Results from Jodrell Banks, England and Adelaide, Austrailia show variations of 12 and 24 hour periods in both speed and direction.

The flights of 7 and 30 November and 5 December were accompanied by successful Langmuir probe measurements. The probe rockets were fired 10 to 15 minutes before the sodium rockets. For the 7 November and 5 December firings, Sporadic-E activity was observed from the ionosphere station at Wallops and was recorded by the Langmuir probe as sharp increases in electron density. During the 30 November flights, a medium sized magnetic storm was in progress and no Sporadic-E was recorded by either the ground station or the rocket probe. Complete analysis of the probe data was delayed until tabulated trajectory information was available. This has now been obtained but interpretation of the data is not yet complete. Initial comparison of the heights and electron densities with wind structure for the three flights has shown no obvious correlation. However, both the electron distribution and wind structure have rapid altitude variations so very exact height measurements are required. When final measurements are available, careful comparisons of electron concentration and wind structure will be made and analyzed according to the various theories which have been proposed.

Positive correlation of winds above 120 km with solar storms has been observed in two flights. The flights of 17 August 1959, and 24 May 1960 occurred during periods of extremely high solar activity. The wind speeds above 120 kms were the greatest ever observed and the general structure is different from the other flights. Apparently the effect is present only during periods of very high activity since many flights have occurred during periods of magnetic storms of low and medium intensity and the winds are not noticeably different from those found during quiet periods.

5.2 GENERAL CLASSIFICATION OF WIND STRUCTURE

Examination of the wind plots shows that they may be grouped into three general classes determined by the velocity variations at different heights.

Class I

Directional changes are numberous but small with wind speed fluctuations of about 30 to 40 m/sec.

Class II

The primary characteristic is one very large change in direction, usually 180°, and the speed at this height varies from 0 to 150 m/sec.

Class III

The structure is characterized by a continuous spiraling change in direction with the wind speed gradually increasing with height until a maximum of about 120 m/sec is reached at about 110 km where the speed drops to about 80 m/sec and remains relatively constant at greater heights.

All flights to date are classified by these characteristics and listed in Table 2. The number of flights in each group is about equal and no season seems to dominate in any group. Class II has more A.M. measurements and Class III has more P.M., but no significance has yet been attached to this fact. The direction of rotation of the spiral motion in Class III is clockwise with height, but again no deductions have been made based on this fact.

5.3 SEASONAL VARIATION

It may be observed from Table 1 or 2 that 11 out of 25 flights occurred during March and April. Also the total number of flights is still relatively small to show positive seasonal trends. However, analyses have been made to see if such trends are indicated.

Figure 23 is a diagram which shows wind direction at various heights for the different seasons. The directions were divided into four quadrants, North to East, North to West, South to East, and South to West.

TABLE 2

CLASS I			CLASS II			CLASS III			
2 March	1962	AM	24 May	1961	PM	20 April	1961	PM	
23 March	1962	PM	9 December	1960	AM	17 April	1962	AM	
27 March	1962	PM	19 April	1961	AM	1 March	1962	PM	
21 April	1961	AM	18 November	1959	PM	16 September	1961	PM	
30 November	1962	AM	17 September	1961	AM	6 June	1962	PM	
5 December	1962	PM	7 November	1962	AM	19 April	1961	PM	(S)
21 February	1963	PM				26 November	1957	AM	(NM)
						20 February	1963	PM	

Note: There was insufficient data to make classification possible for 20 April 1961 at Sardinia (S); 12 October 1955 and 11 April 1956 at New Mexico (NM); and 17 August 1959 at Wallops.

Spring included February, March, April, summer included May, June, July, fall included August, September, October and winter included November, December and January. The closed areas indicate height intervals at which winds have been measured in the designated quadrants. It is noted that the closed areas for each season is nearly proportional to the number of measurements during that season, so that no seasonal trend is indicated.

The height, direction and magnitude of the greatest wind speed observed for each flight is shown in Figure 24. Most observations showed speeds of over 100 m/sec at some height between 90 and 140 km, and there seems to be a preferential direction of SE but no season dominates.

In general, no strong seasonal trend has been found in the data available and it may be expected that many more observations are required before positive identification of such variations.

5.4 DIURAL VARIATIONS

In some ways the data is more suited to a study of diural rather seasonal variations. Although all measurements are made during twilight, there are about equal numbers of observations during morning and evening. Attempts to show any diurnal effects in the data were completely unsuccessful until after the series of flights in April 1961 from Wallops Island and Sardinia. The time of firings of this series which included five flights and the time difference in hours is shown in Table 3.

TABLE 3

TIME OF OBSERVATION FOR THE APRIL 1961 SERIES

NUMBER	SITE	APPROXIMATE LMT	APPROXIMATE EST
5	Wallops	19 April 04^h 36^m	19 April 04.6 hours
6	Sardinia	19 April 19 12	19 April 13.5
7	Sardinia	20 April 04 36	19 April 22.9
8	Wallops	20 April 19 12	20 April 19.2
9	Wallops	21 April 04 39	21 April 04.6

DIFFERENCE IN TIME

1-2 = 8.9 hours	1-2 = 8.9 hours	1 = 0
2-3 = 9.4	2-4 = 29.7	2 = 8.9
3-4 = 20.3	4-5 = 9.4	3 = 18.3
		4 = 38.6
		5 = 48.0

The analysis is based on the periodic variations obtained from the radar meteor observations. The series of five sequential firings was used to investigate a periodic effect. The wind velocity at any height may be represented on a polar plot by a vector with length equal to the speed and pointed in the wind direction. Such plots were made at selected heights for the five consecutive firings in April, 1961. It was found that the end of these vectors could be joined in sequence by a continuous, smooth curve going in a counterclockwise direction. This direction is indicated from the meteor data and also is the shortest path to connect the vector end points. These points are shown in Figures 25 thru 39 connected by solid lines. During 16-17 September 1961 and 1-2 March 1962 sequential observations from Wallops Island were obtained with time difference of 11.4 and 12.5 hours. Vectors from these flights were also placed on the plots and a continuation of the curve could be sequentially drawn through them at all heights.

A true periodic pattern must be represented by a closed figure. The dotted lines in Figure 25 thru 39 represent a continuation of the solid line curve into a closed figure using the sequential firings of September, 1961 and March, 1962 as guides and using a counterclockwise direction. It is interesting that such a closed pattern could be drawn at all heights. All of the available data was then added to the plot and most of the scattered observations fit on the originally drawn curves with no changes at all. With only slight adjustments, all data to date is represented on the included figures. Table 4 lists the data

TABLE 4

No.	Date	Twilight	Range of Height in km
1	17 August 1959	AM	140-220
2	18 November 1959	PM	94-163
3	24 May 1960	PM	84-169
4	9 December 1960	AM	90-138
5	19 April 1961	AM	92-154
6	19 April 1961	PM S*	83-183
7	20 April 1961	AM S*	108-189
8	20 April 1961	PM	81-165
9	21 April 1961	AM	82-162
10	16 September 1961	PM	78-146
11	17 September 1961	AM	96-172
12	1 March 1962	PM	71-126
13	2 March 1962	AM	65-127
14	23 March 1962	PM	59-140
15	27 March 1962	PM	80-118
16	17 April 1962	AM	76-191
17	6 June 1962	PM	56-137
18	7 November 1962	AM	68-152
19	30 November 1962	AM	77-157
20	5 December 1962	PM	83-138
21	20 February 1963	PM	58-151
22	21 February 1963	PM	83-164
23	26 November 1957	AM	104-202
24	11 April 1956	PM	77-105

*S = sardinia

corresponding to the numbers on the figures. The only data which does not reasonably fit this representation is that observed during periods of extremely high solar activity.

It may be noted that the figures at all heights are much alike. They closely resemble a figure attributed to Pascal called a limicon. The figure is generated from the equation:

$$\rho = b - a \cos \theta$$

The data limicons do not fit this formula exactly since they are not symetrical and are displaced from the origin. However, the relation may be of some value in analyzing the figure. Each height has a rotation of the axis which can be added to the equation as a phase angle. This phase angle or direction of the limicon axis is plotted by various heights in Figure 40. It is interesting to note that this direction change is continuous with height, though no physical significance has yet been connected with this direction. The quantities "b" and "a" are also constant for a particular height.

The function $\rho = a \sin \frac{1}{2} \theta$, also describes some of the characteristics of the data figures, but again no meaningful analysis has been obtained from the expression.

In general, no physical significance has been found for this method of data presentation. The figures do describe the available data and utilize the counter clockwise rotation of the periodic effects reported from radar meteor data. The figures are similar to what might be expected from two out of phase cyclic motions which in the upper atmosphere could be due to tidal and heating effects. The method of presentation has also demonstrated some ability to predict since the most recent five flights were added after the figures were drawn. As more data becomes available, a thorough theoretical analysis of this model may be desirable.

Section 6

SUMMARY

During the period covered by this report, the major effort was directed toward coordinated firings with other rocket techniques and from other sites. A total of thirteen vapor trail rockets were launched from Wallops Island. Wind data was obtained from eleven of these. Second stage failure of Nike-Asps occurred during two flights. Due to extended periods of cloudy weather, field trips were much longer and more expensive than anticipated. This reduced the funds and time available for data analysis. Wind data from all of the flights has been reduced and included in this report. Some analysis of the total available wind data was also done. Planned analysis of diffusion and turbulence data was necessarily limited. The data was taken and proposals for continuation of this investigation included complete reduction and analysis of this data.

SECTION 7

RECOMMENDATIONS

Proposals for continuation of this program have been submitted and contractual negotiations have begun. Briefly the continuation includes:

(1) Coordiated firings at Wallops Island and Fort Churchill and with other sites during an international program of wind study.

(2) Continued collection of wind data and analysis to obtain models of large and small scale circulation.

(3) Increased emphasis on measurements of diffusion to determine seasonal or diurnal effects.

(4) Continued investigation of turbulence near and below the 100 km region.

(5) Increase emphasis on measurement of temperature with diffusion.

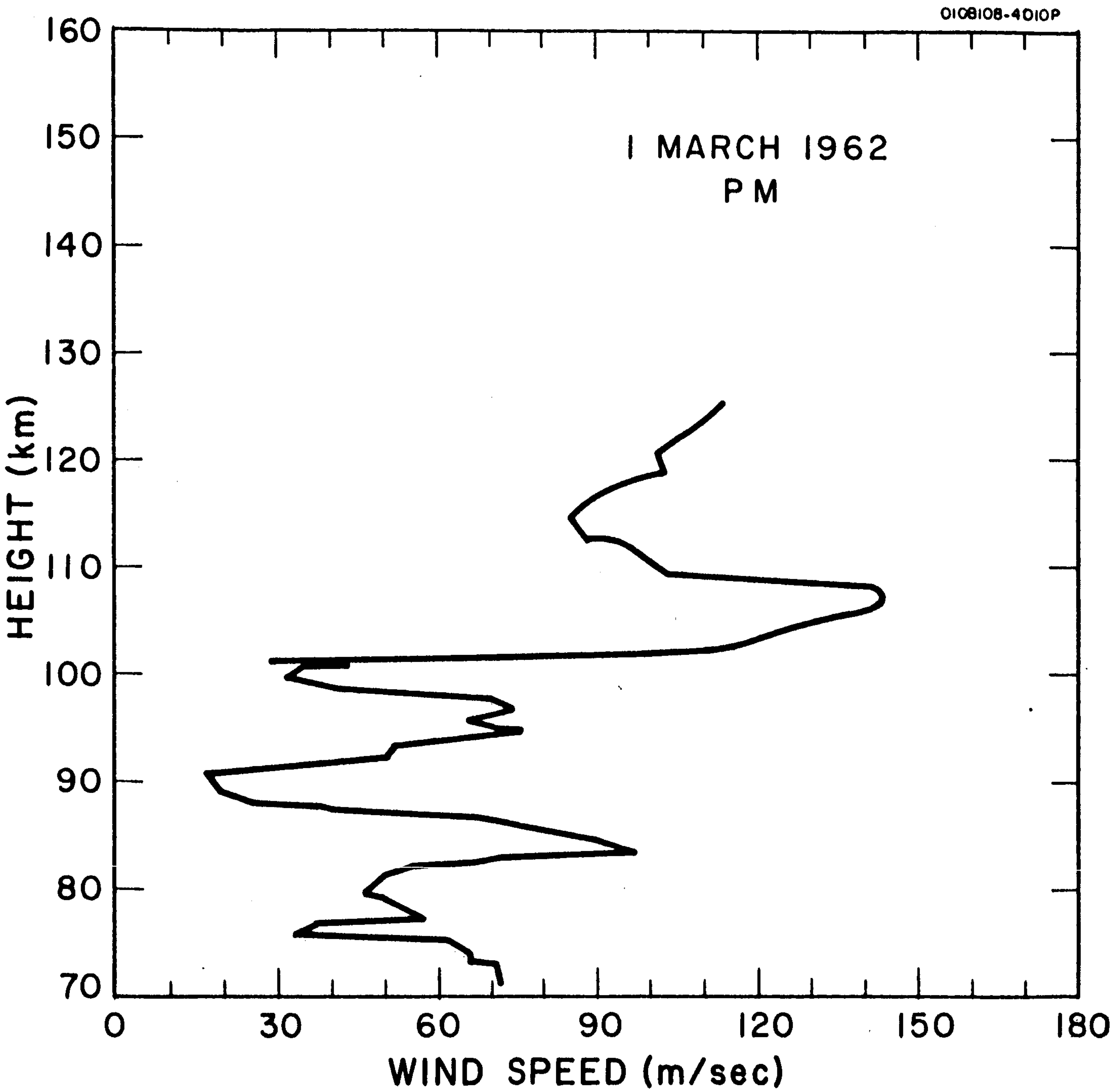

Figure 1. Change of wind speed with height for evening twilight of 1 March 1962 at Wallops Island.

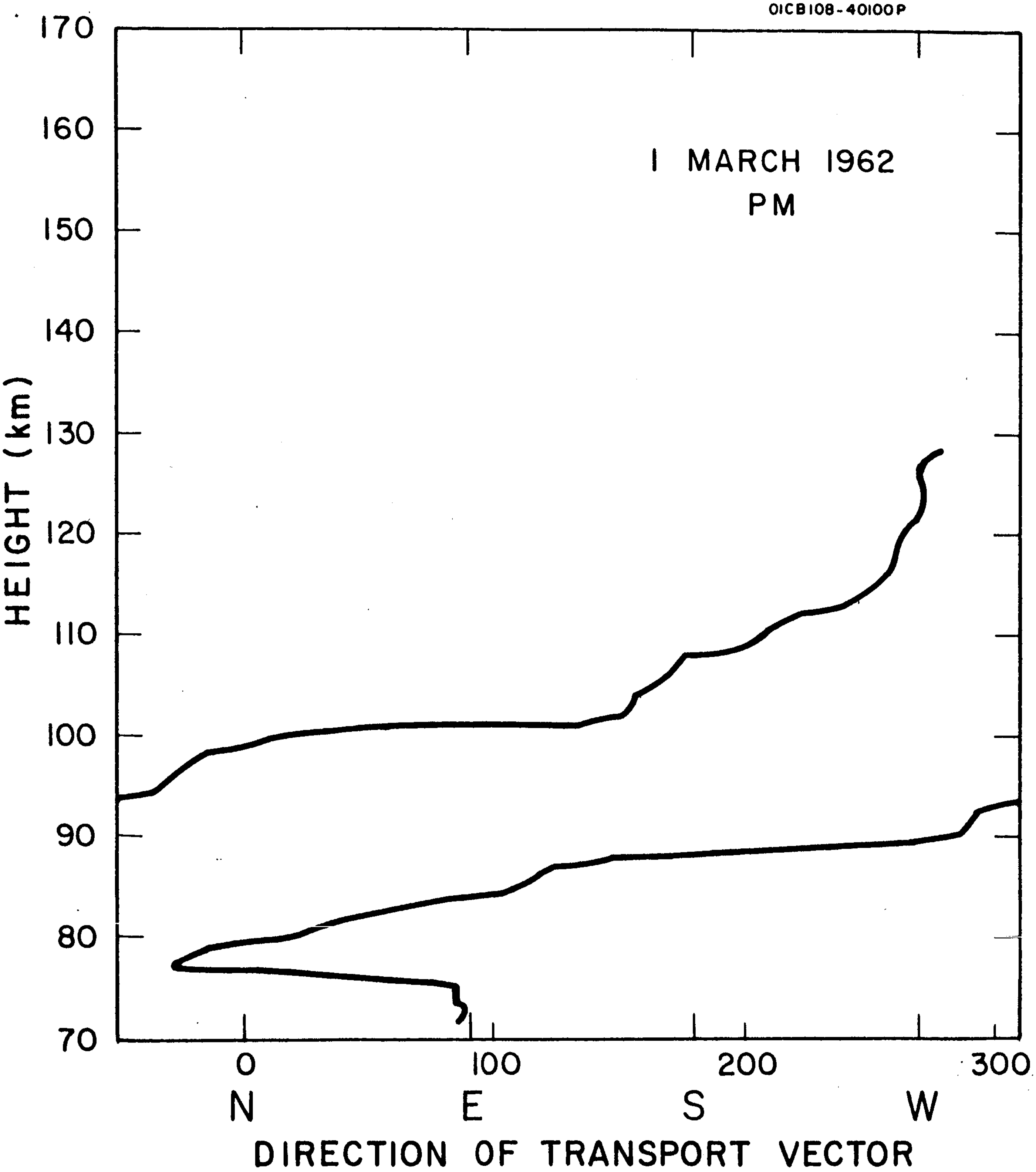

Figure 2. Change of direction of transport vector with height for evening twilight of 1 March 1962 at Wallops Island.

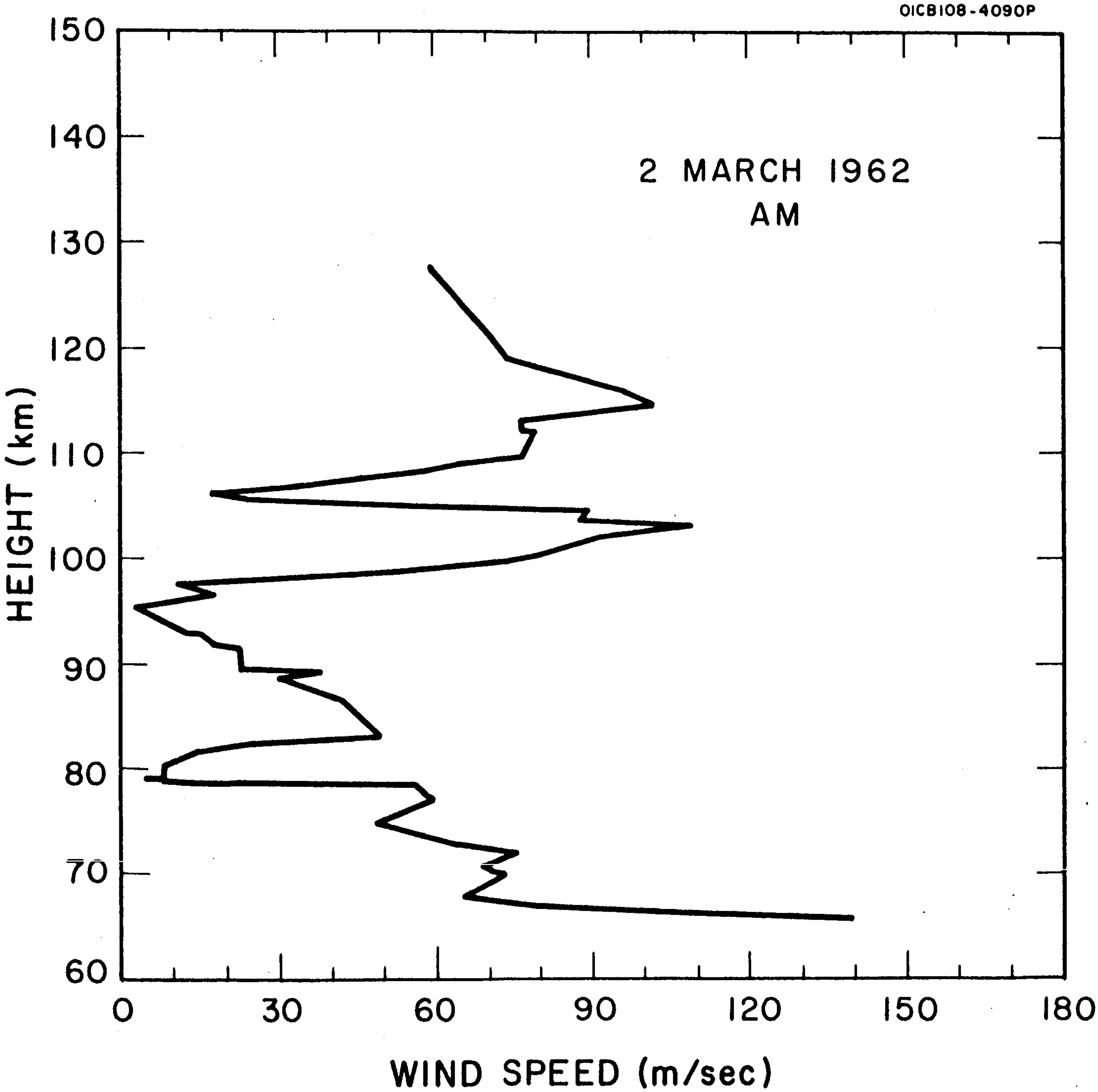

Figure 3. Change of wind speed with height for morning twilight of 2 March 1962 at Wallops Island.

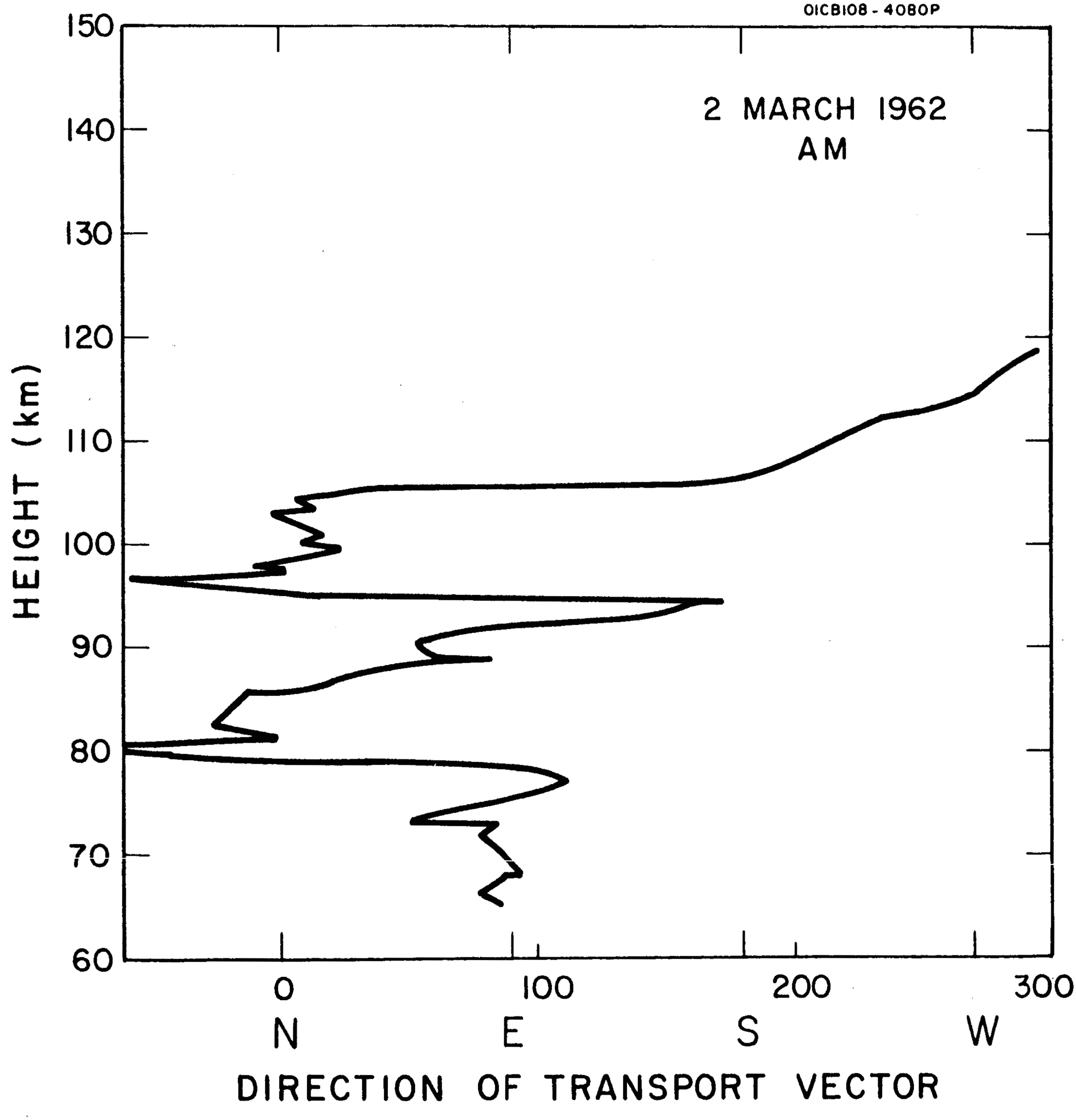

Figure 4. Change of direction of transport vector with height for morning twilight of 2 March 1962 at Wallops Island.

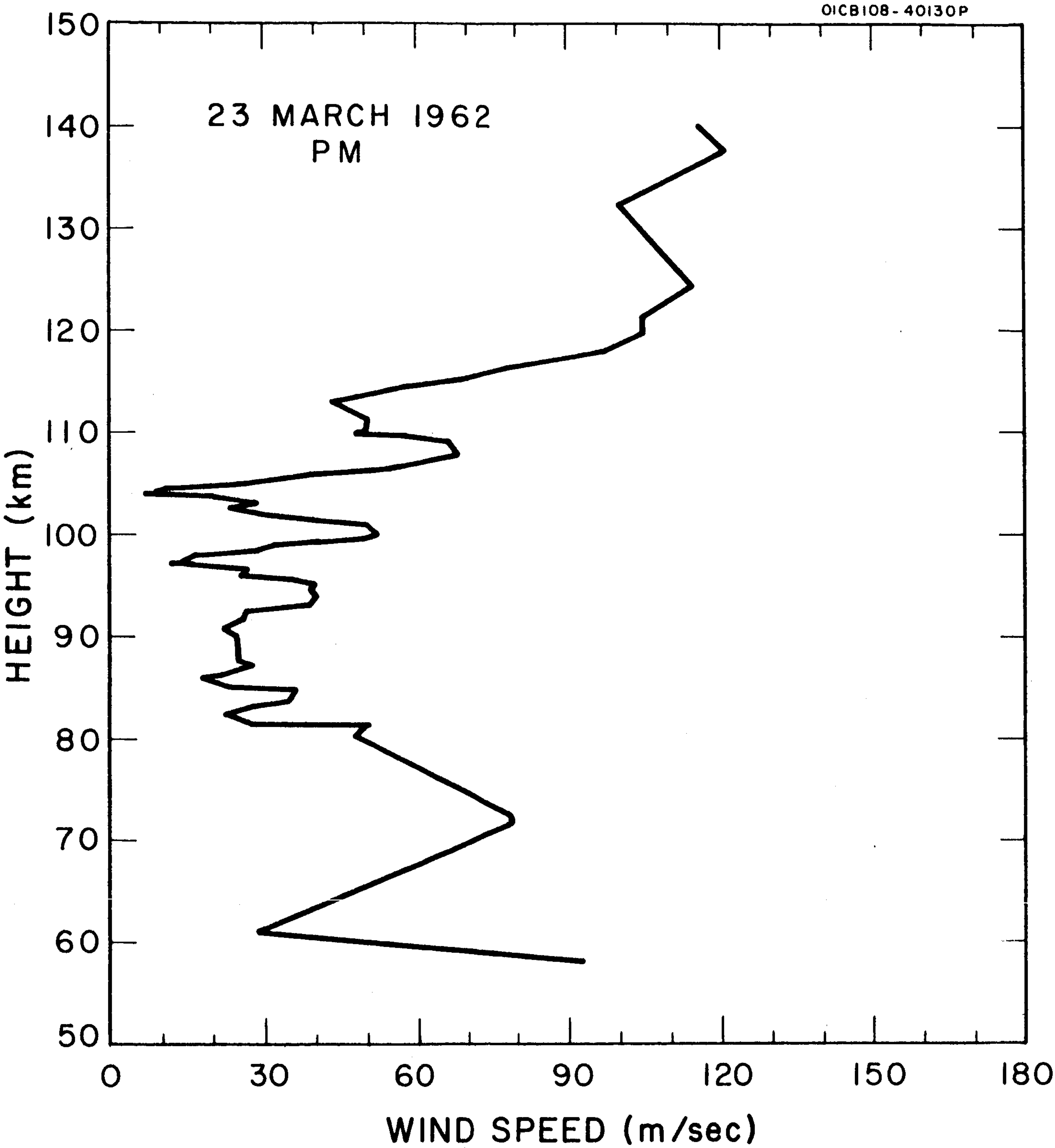

Figure 5. Change of wind speed with height for evening twilight of 23 March 1962 at Wallops Island.

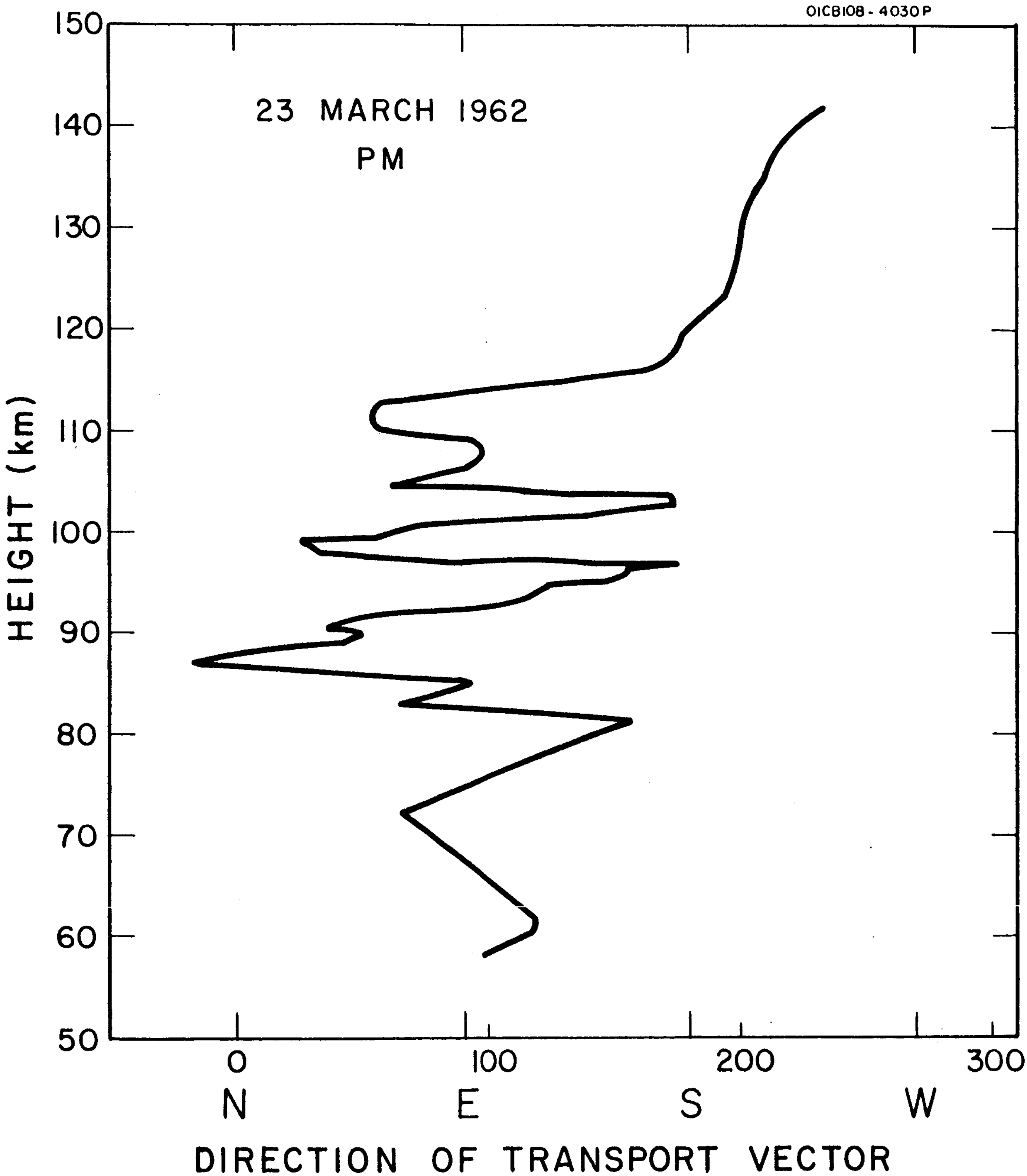

Figure 6. Change of direction of transport vector with height for evening twilight of 23 March 1962 at Wallops Island.

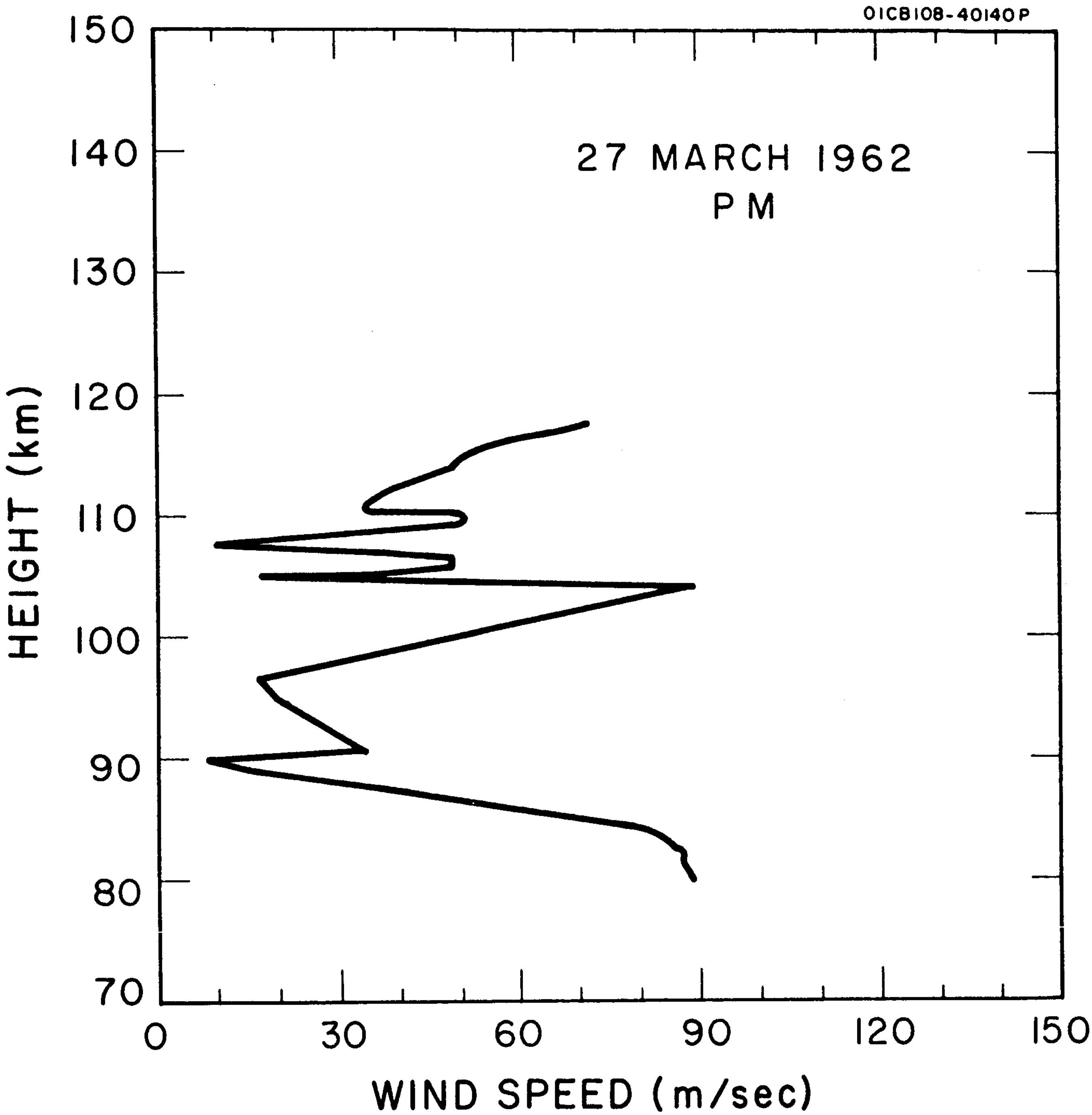

Figure 7. Change of wind speed with height for evening twilight of 27 March 1962 at Wallops Island.

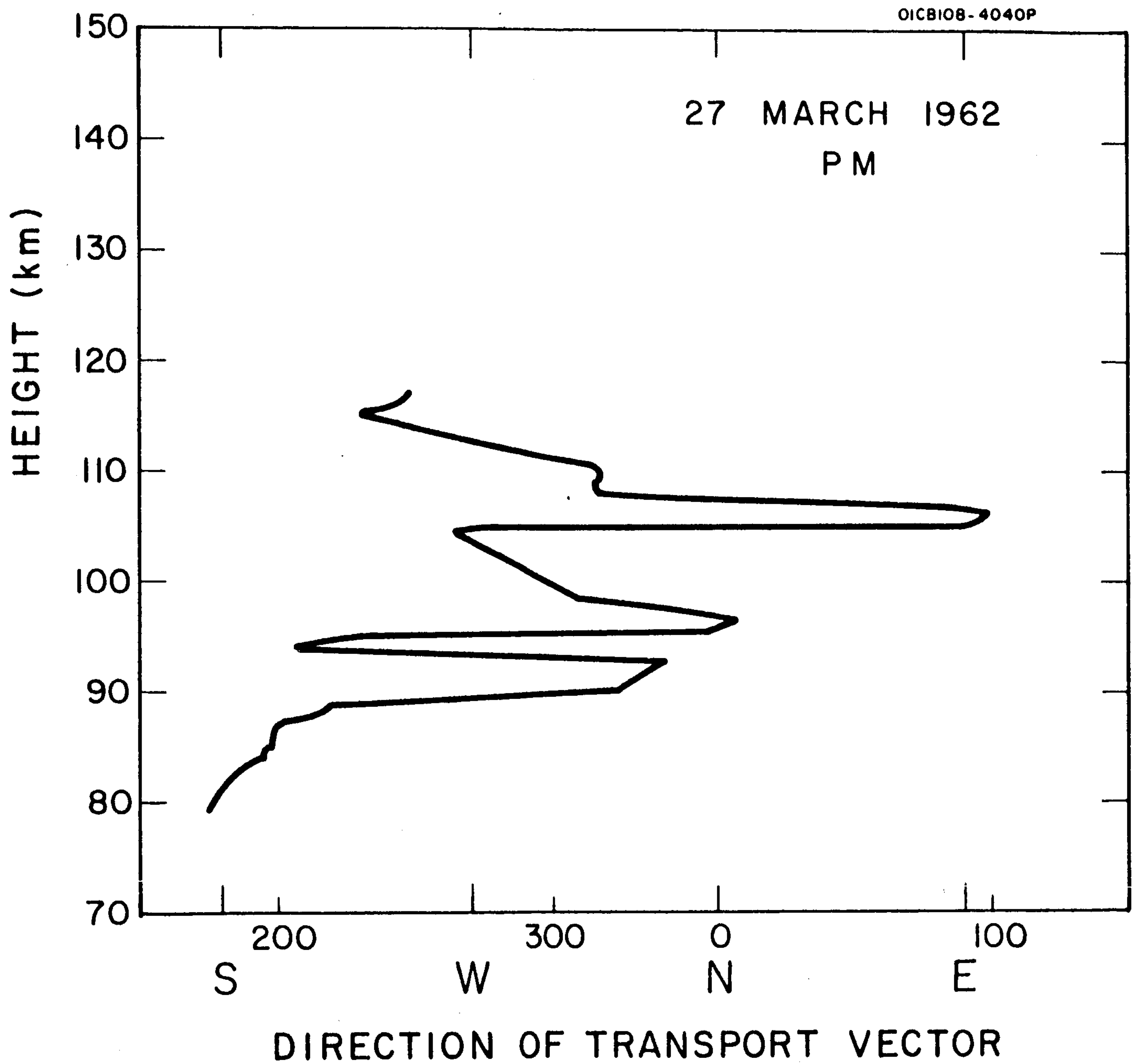

Figure 8. Change of transport vector with height for evening twilight of 27 March 1962 at Wallops Island.

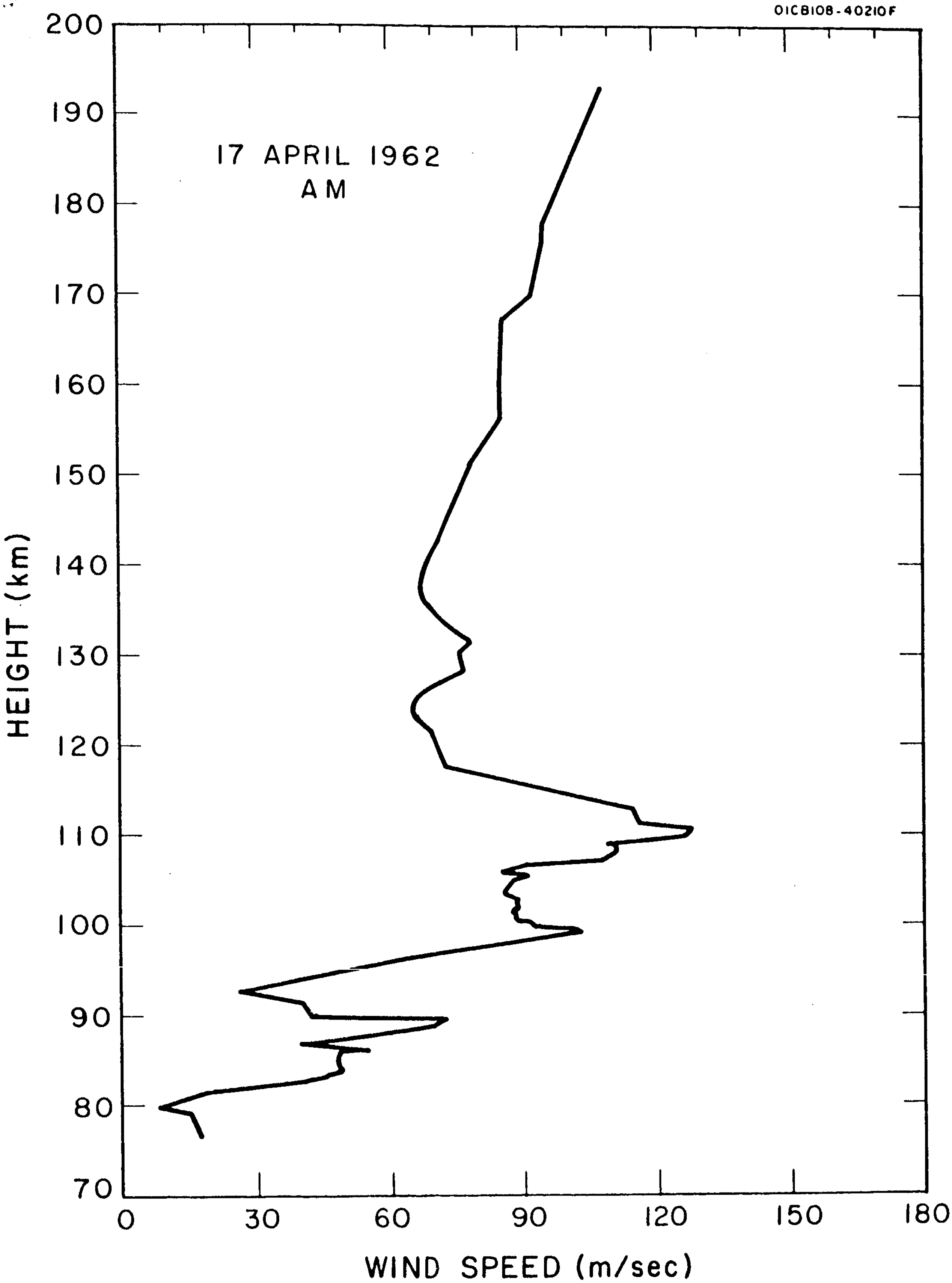

Figure 9. Change of wind speed with height for morning twilight of 17 April 1962 at Wallops Island.

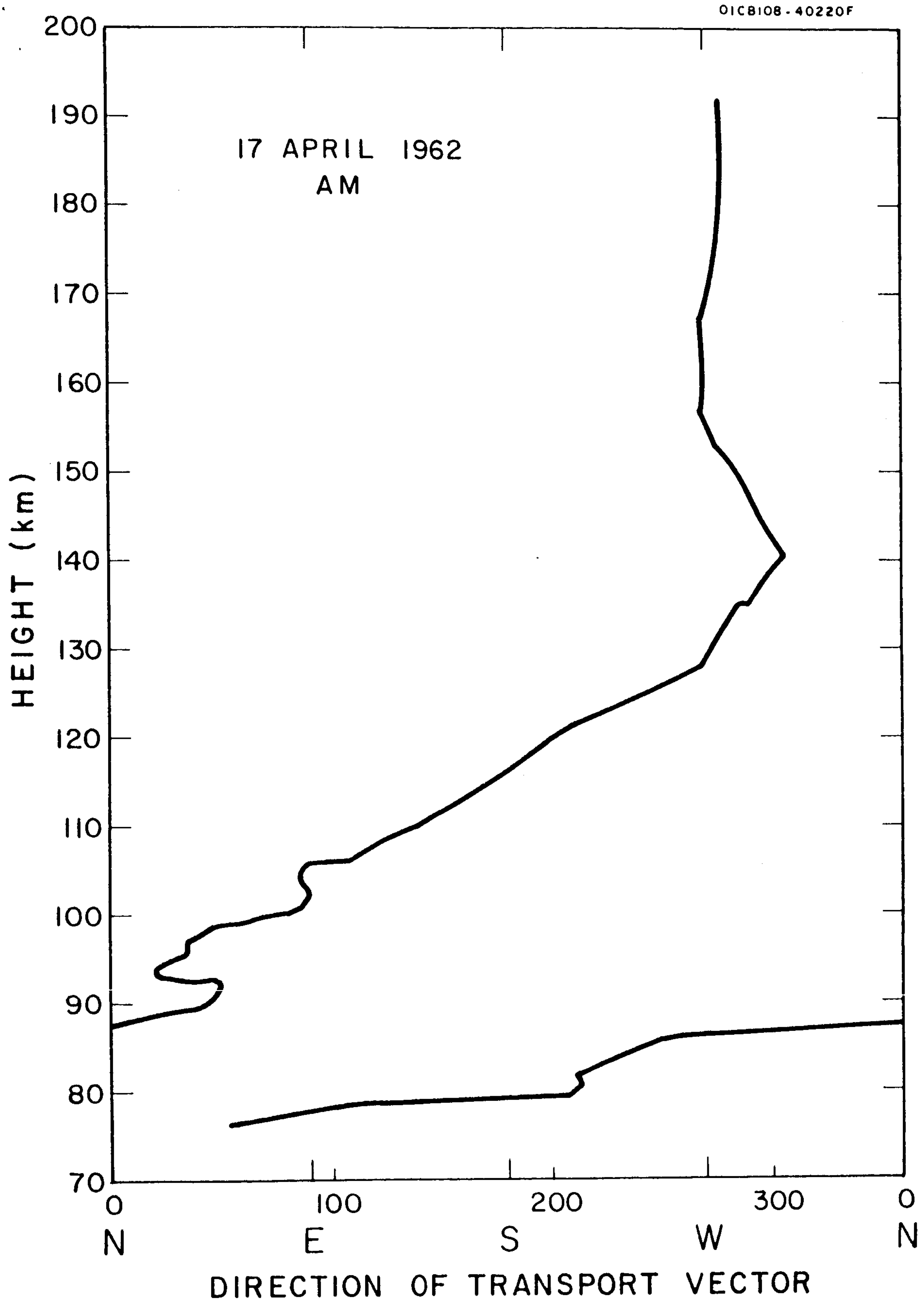

Figure 10. Change of direction of transport vector with height for morning twilight of 17 April 1962 at Wallops Island.

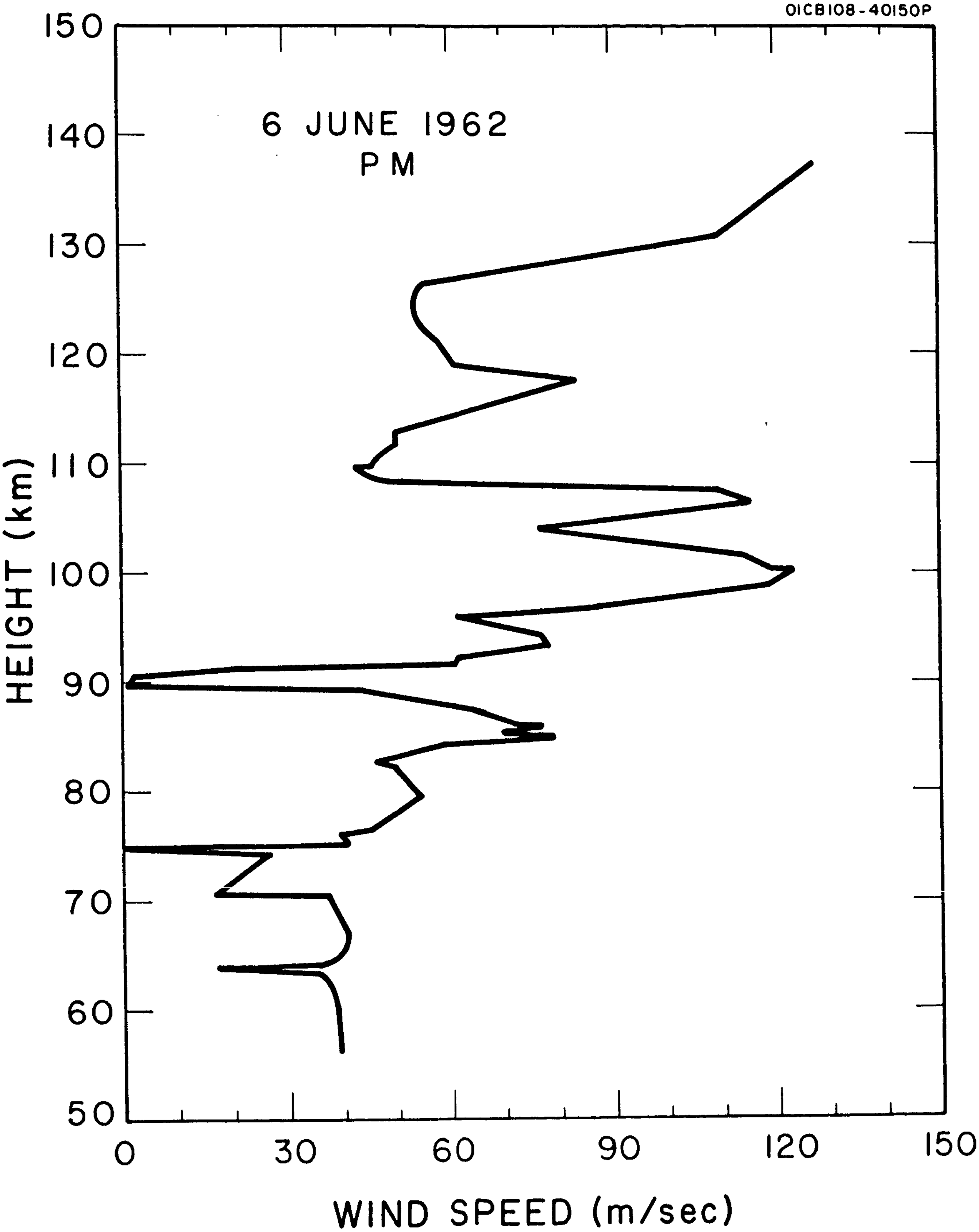

Figure 11. Change of wind speed with height for evening twilight of 6 June 1962 at Wallops Island.

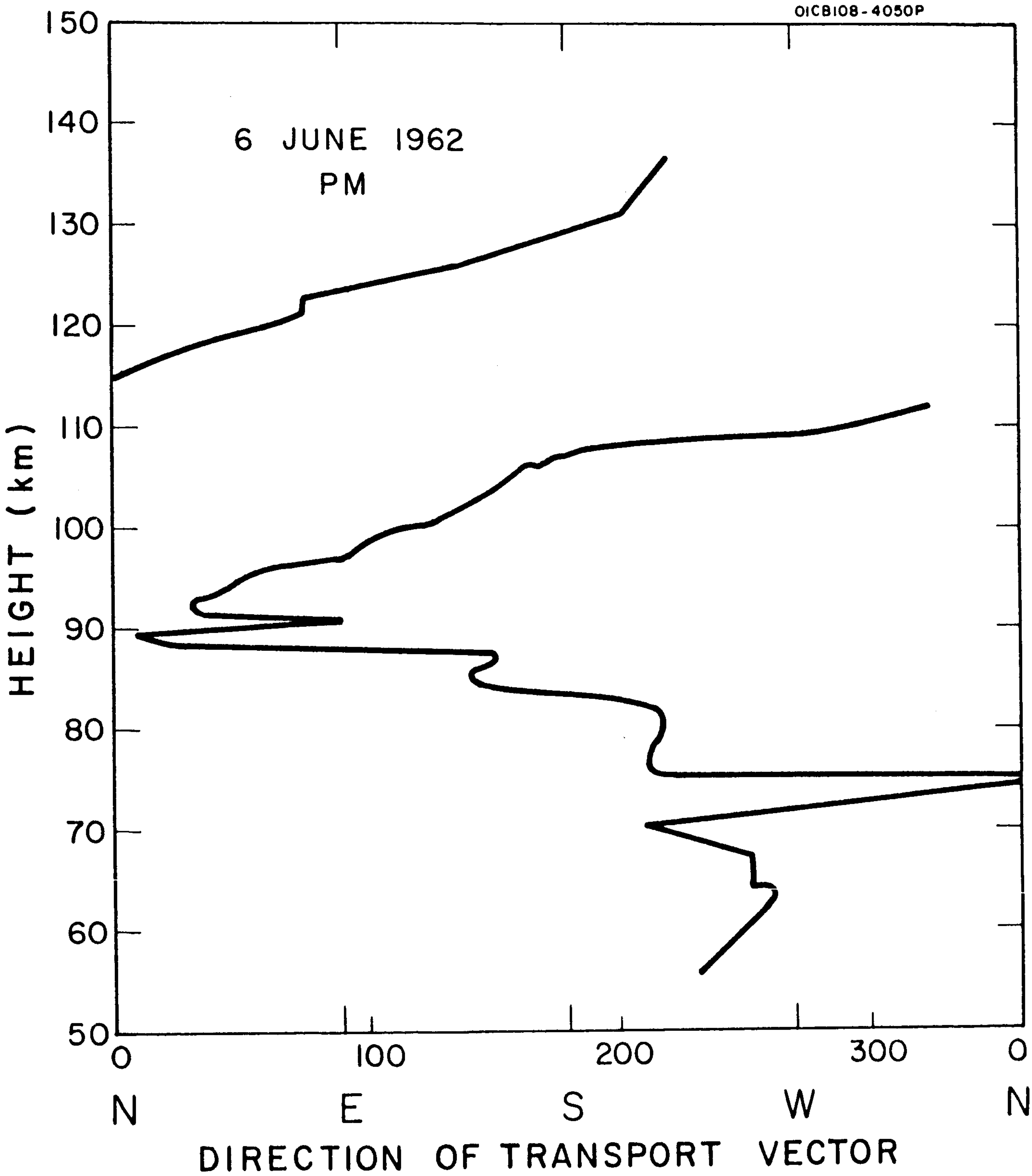

Figure 12. Change of direction of transport vector with height for evening twilight of 6 June 1962 at Wallops Island.

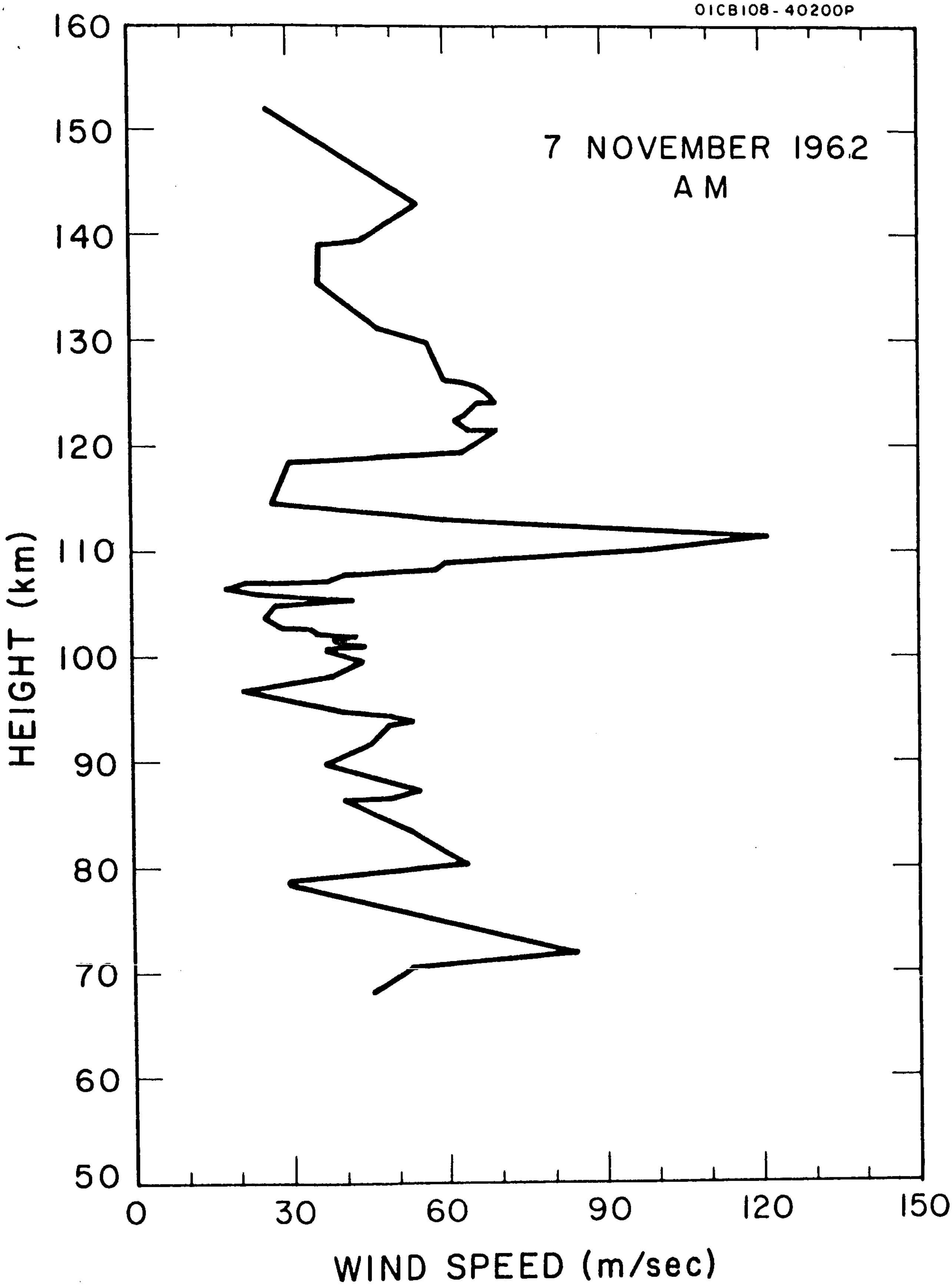

Figure 13. Change of wind speed with height for morning twilight of 7 November 1962 at Wallops Island.

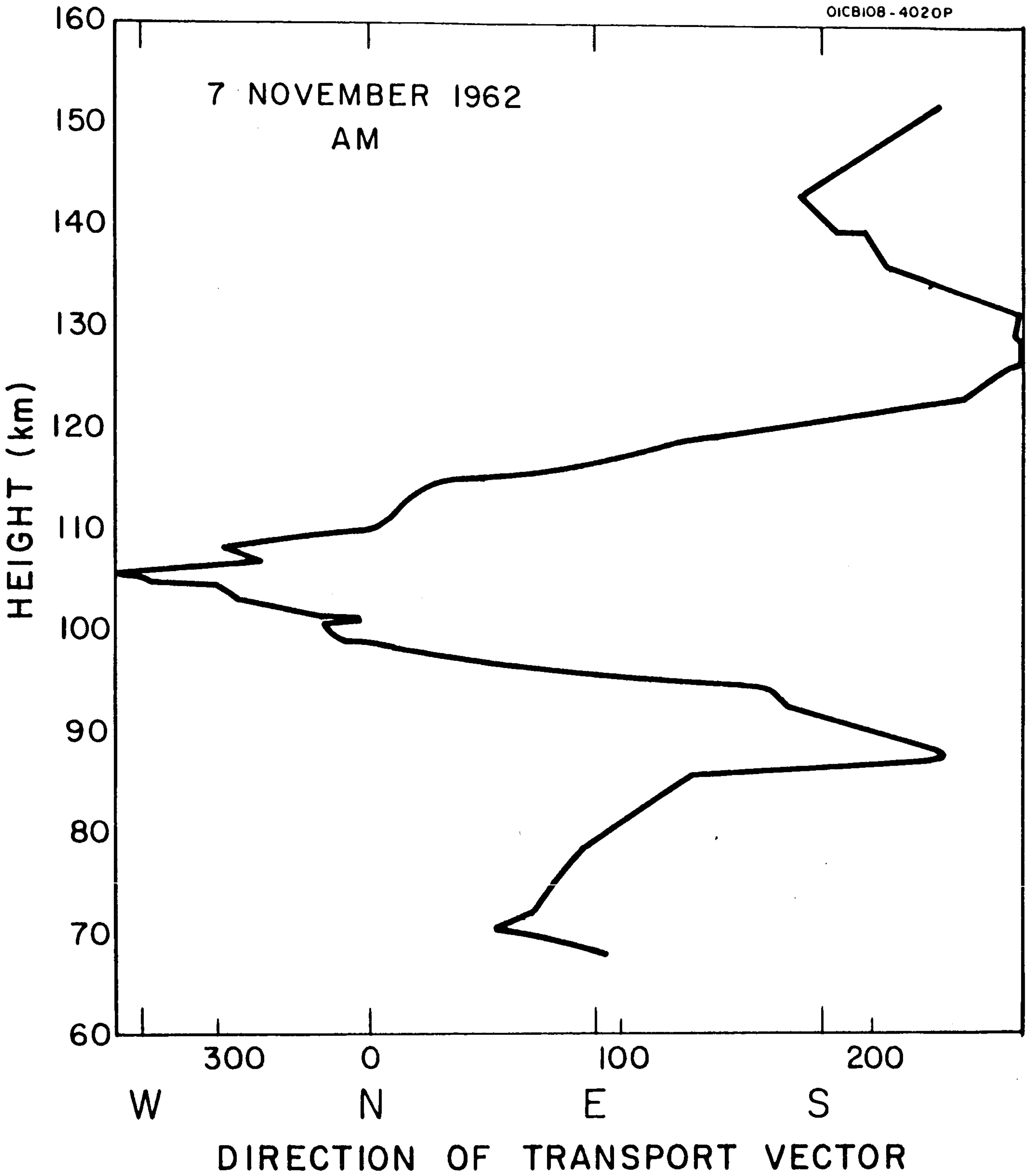

Figure 14. Change of direction of transport vector with height for morning twilight of 7 November 1962 at Wallops Island.

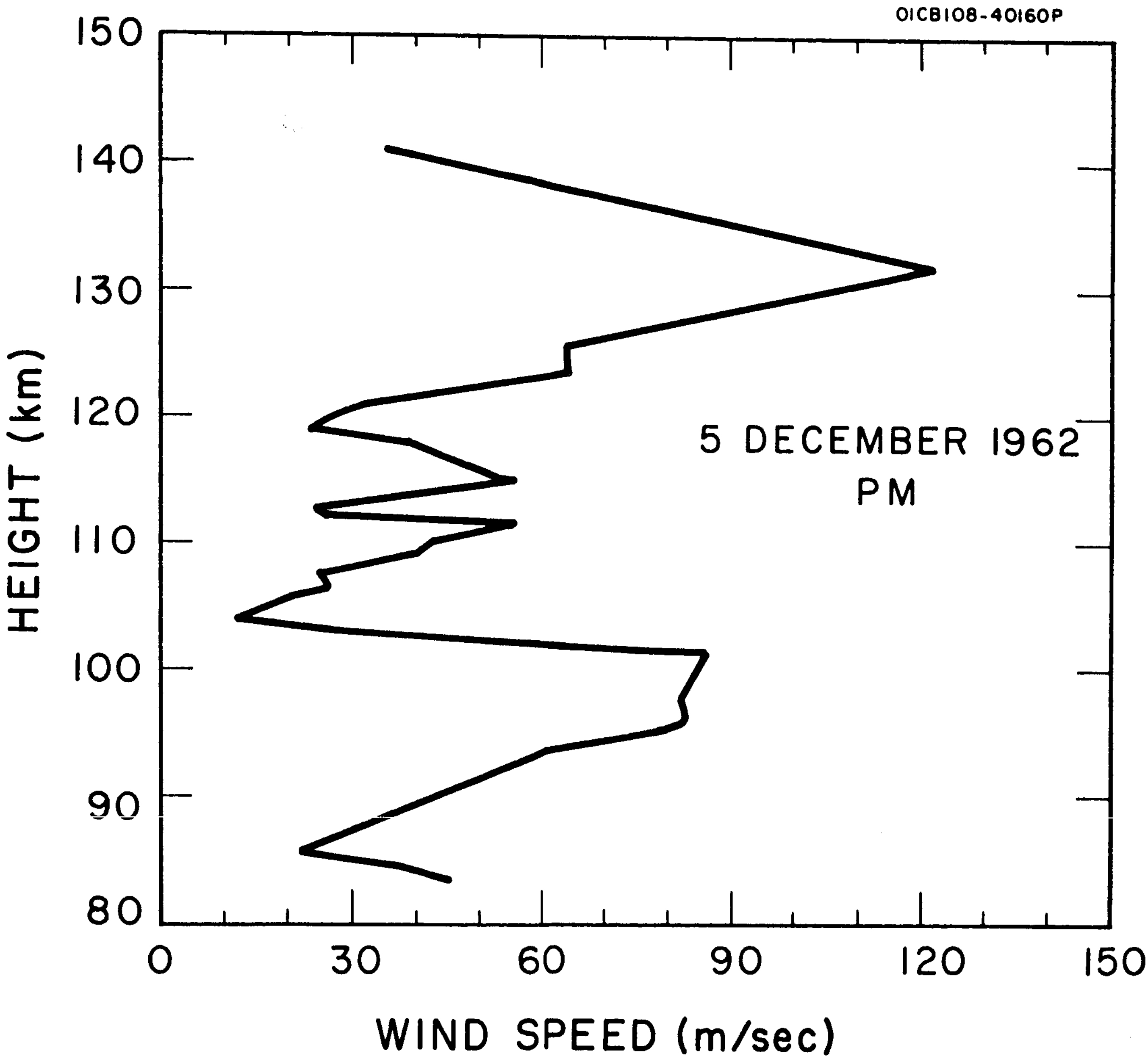

Figure 15. Change of wind speed with height for evening twilight of 5 December 1962 at Wallops Island.

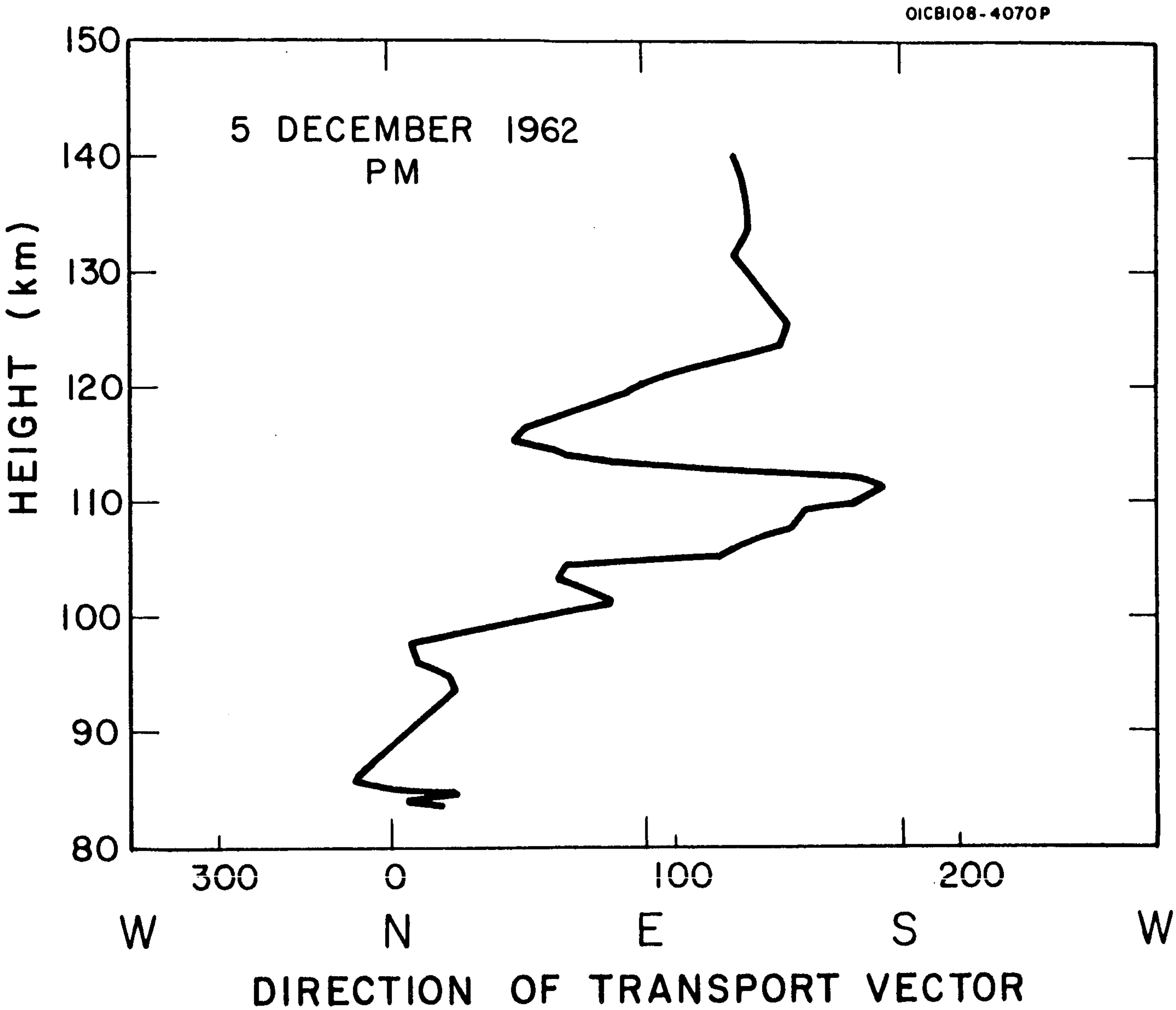

Figure 16. Change of direction of transport vector with height for evening twilight of 5 December 1962 at Wallops Island.

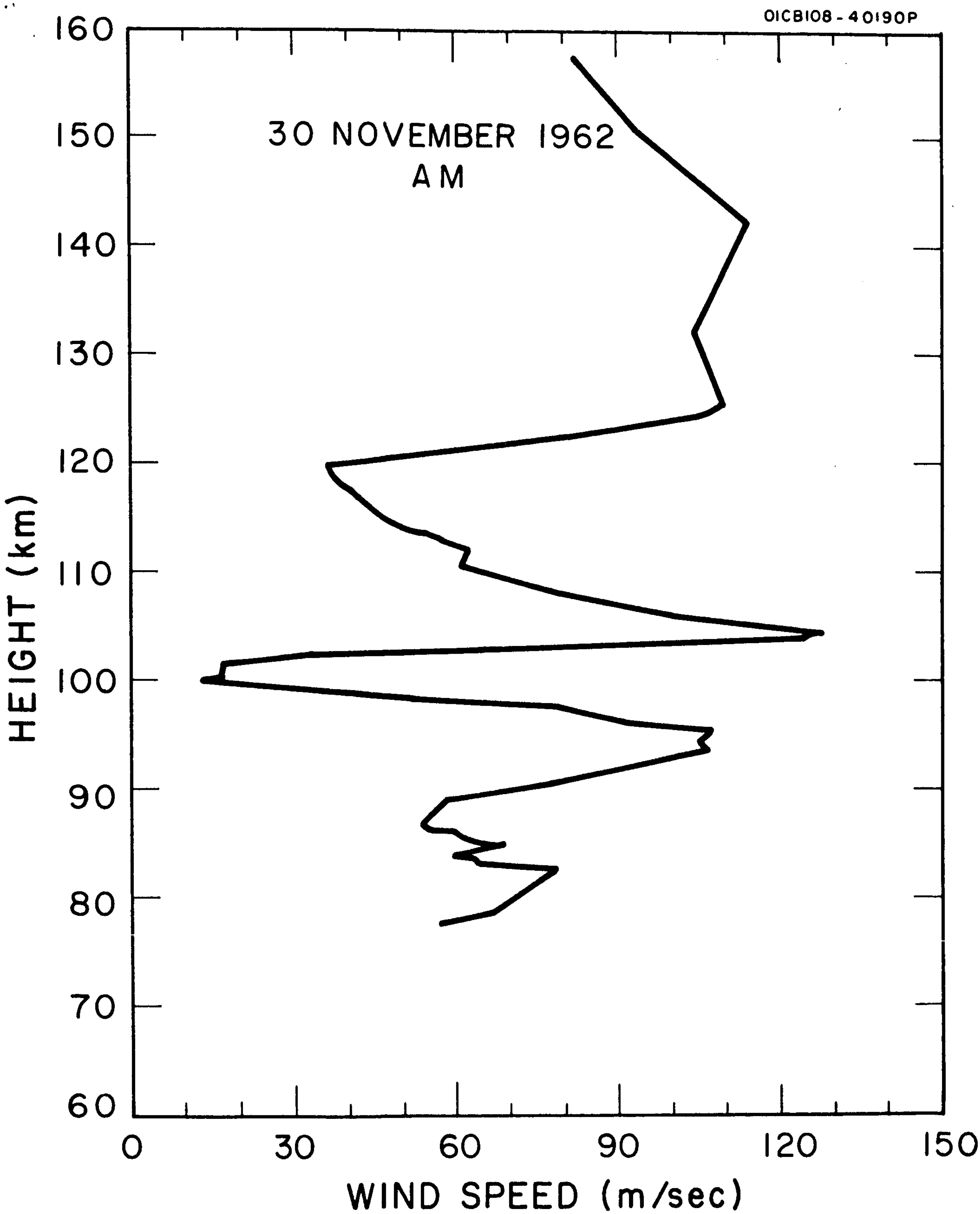

Figure 17. Change of wind speed with height for morning twilight of 30 November 1962 at Wallops Island.

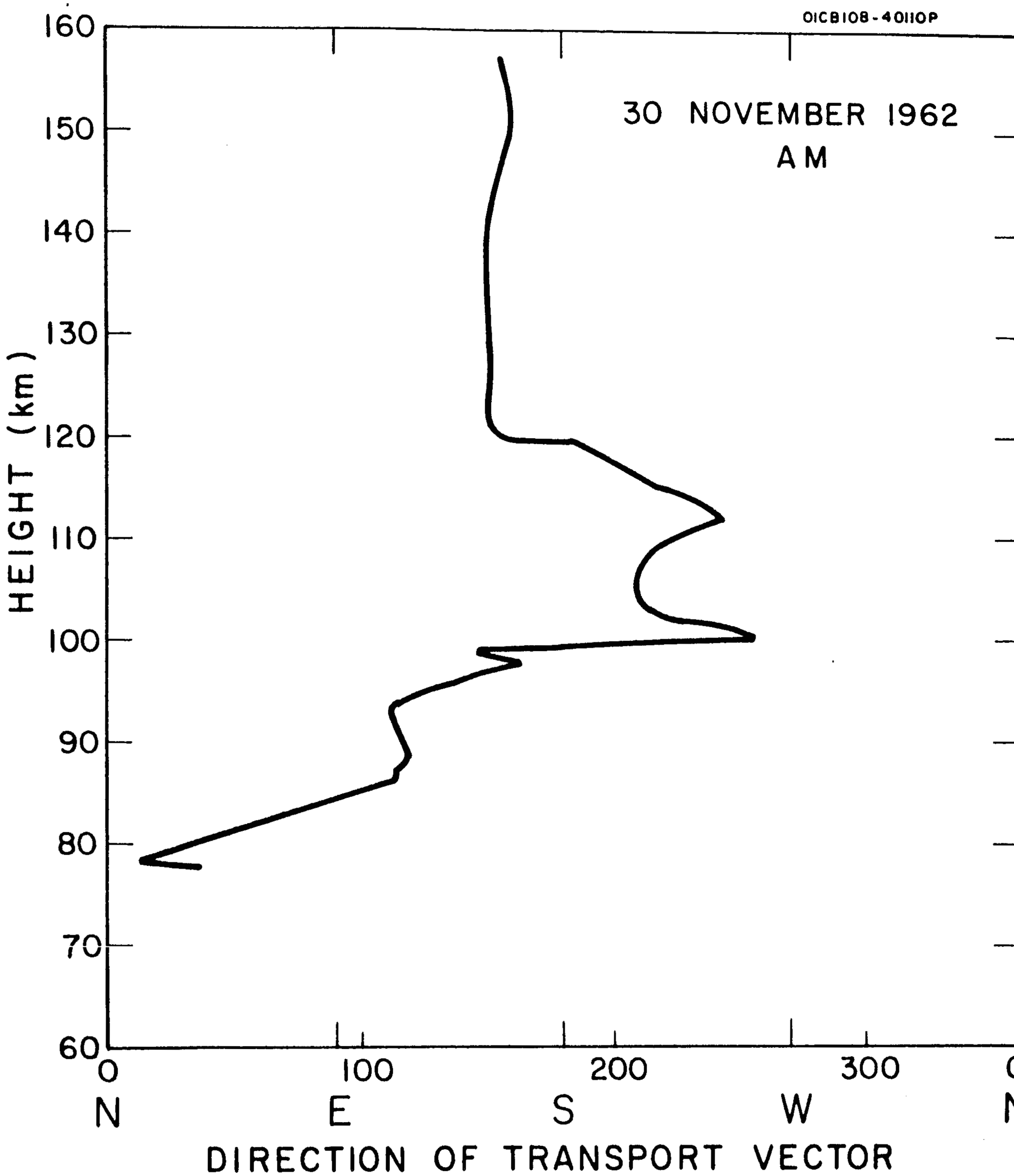

Figure 18. Change of direction of transport vector with height for morning twilight of 30 November 1962 at Wallops Island.

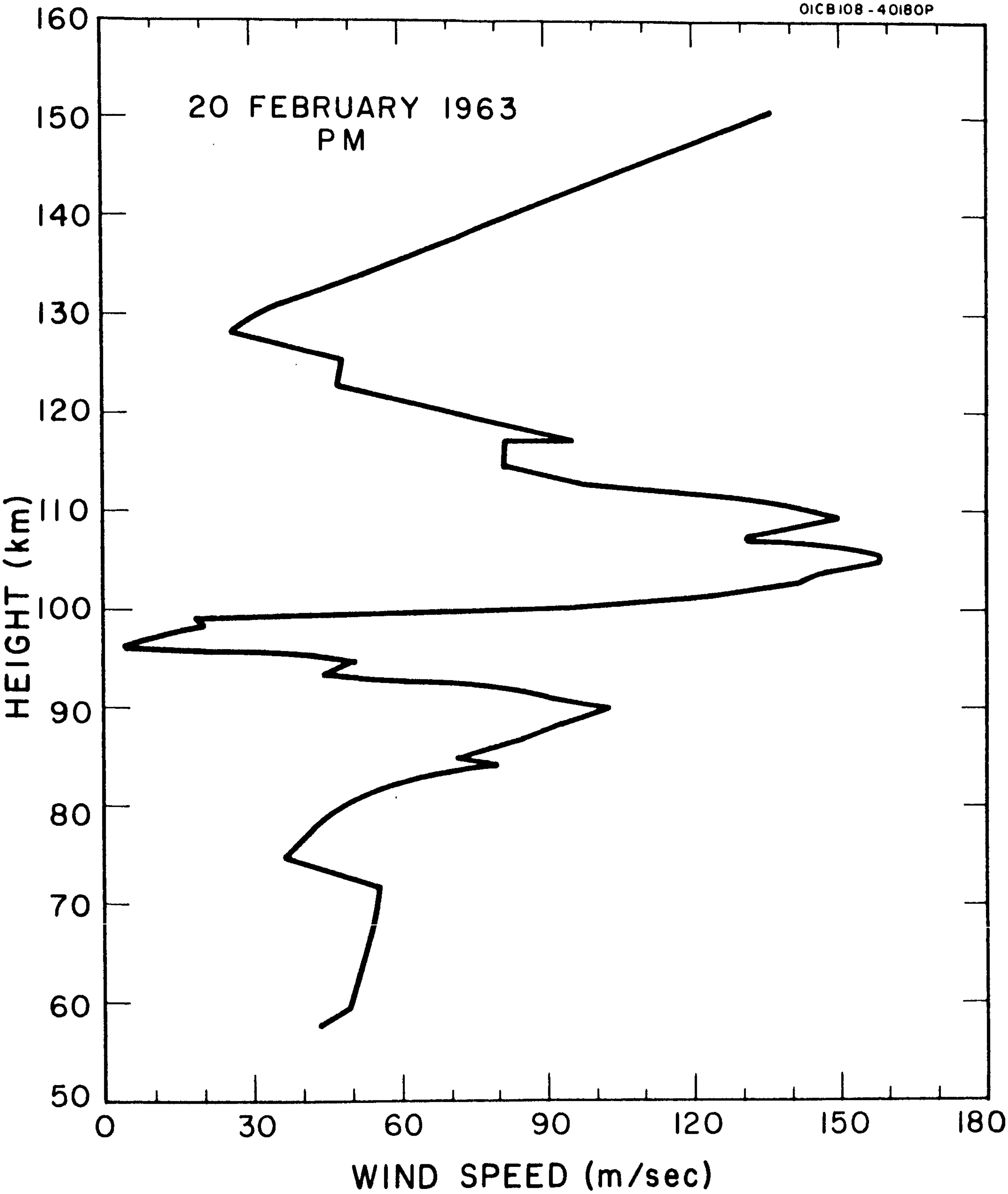

Figure 19. Change of wind speed with height for evening twilight of 20 February 1963 at Wallops Island.

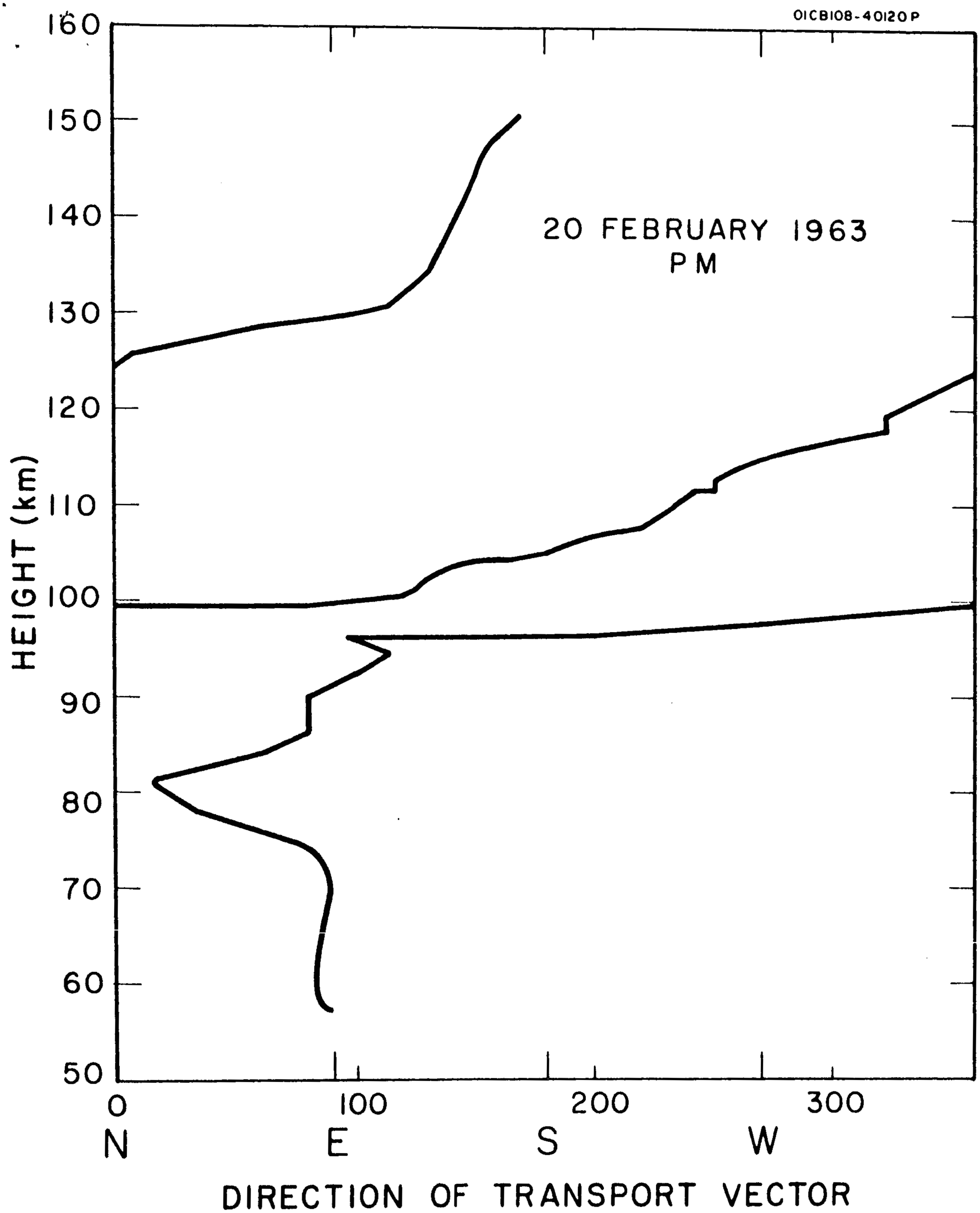

Figure 20. Change of direction of transport vector with height for evening twilight of 20 February 1963 at Wallops Island.

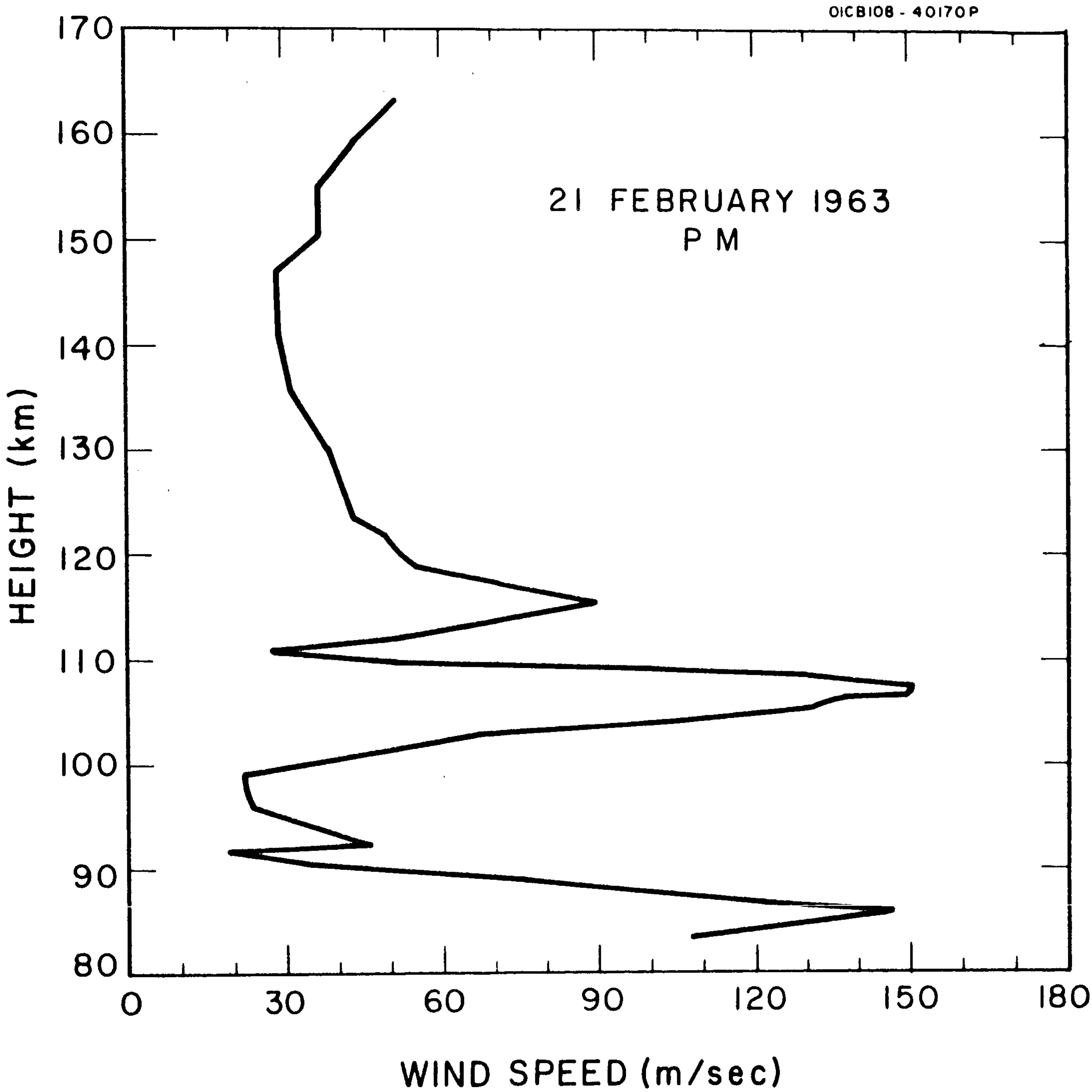

Figure 21. Change of wind speed with height for evening twilight of 21 February 1963 at Wallops Island.

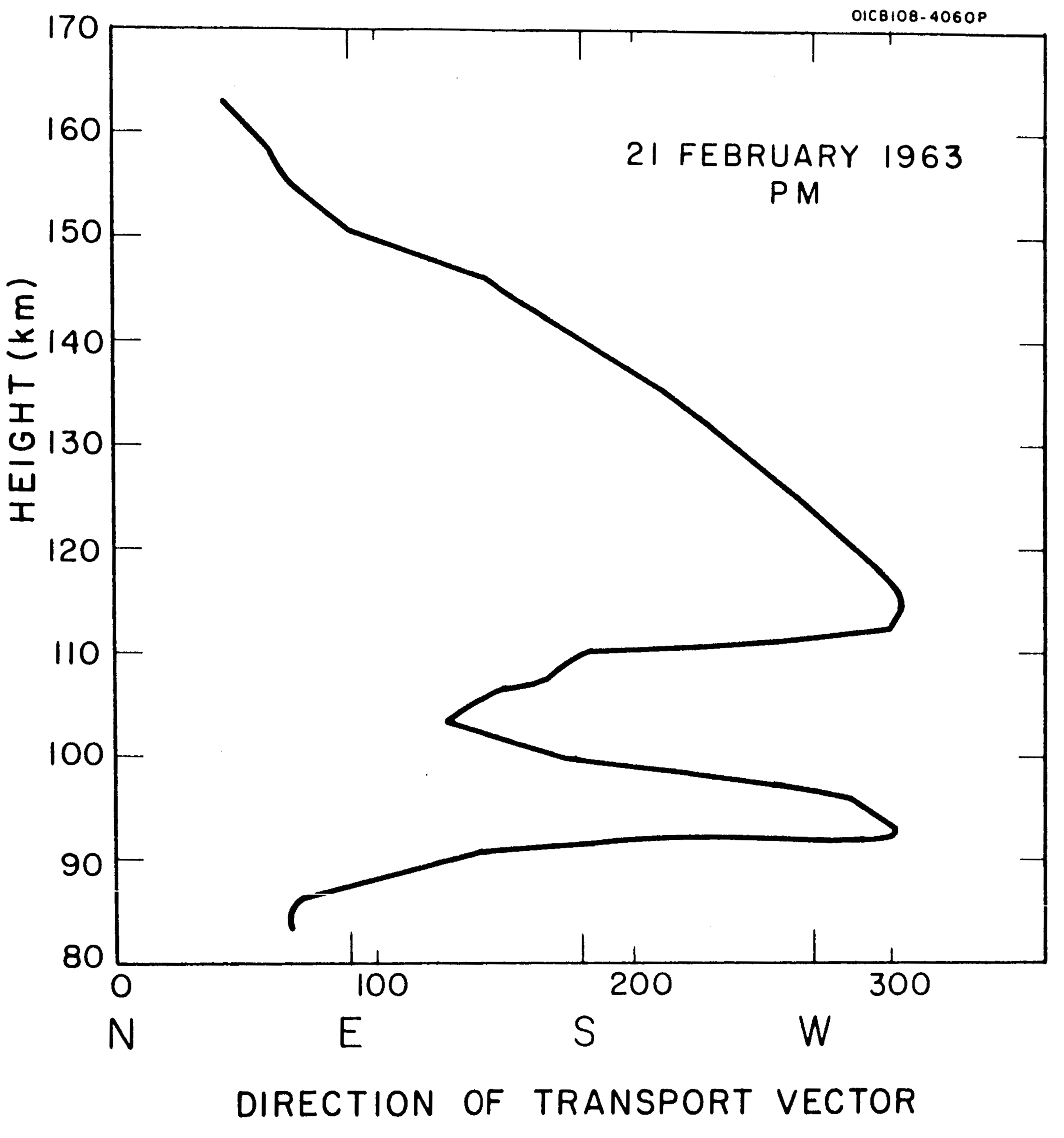

Figure 22. Change of direction of transport vector with height of evening twilight of 21 February 1963 at Wallops Island.

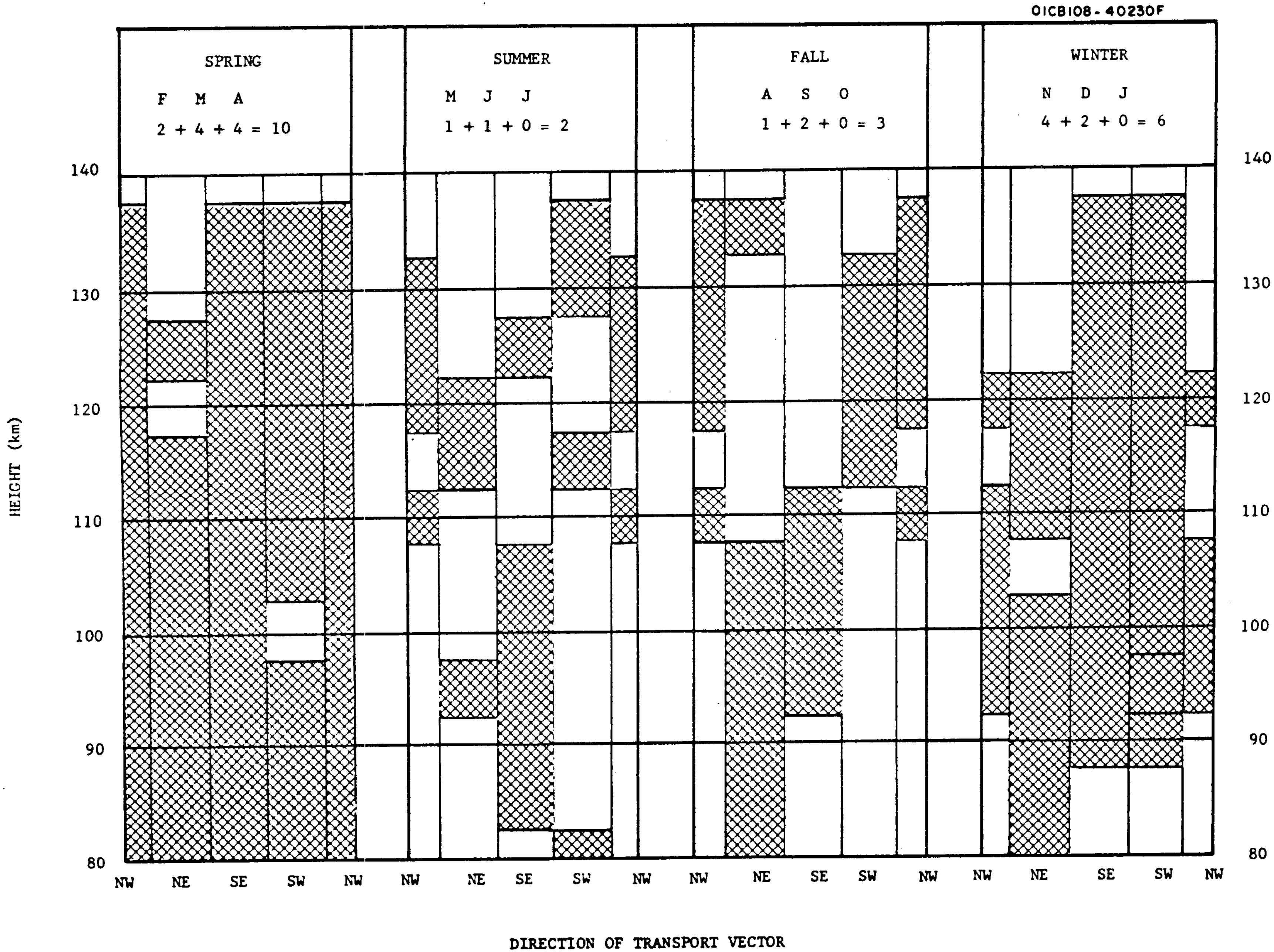

Figure 23. Direction of the transport vector for the wind at various heights for different seasons. The crosshatched areas represent the observations and the open areas show where no wind has been observed. The number of observations for each month is indicated along with the total for each season.

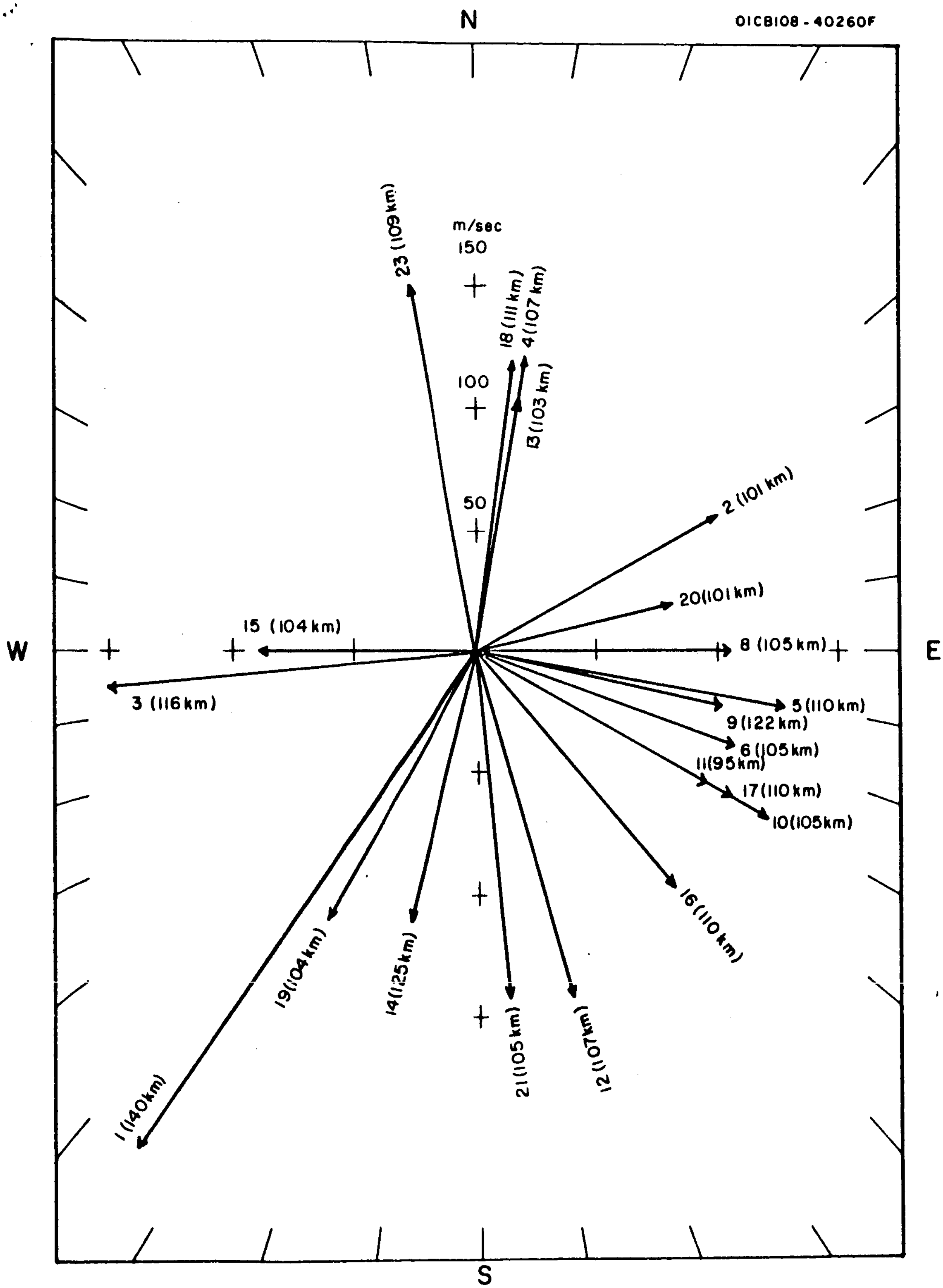

Figure 24. The height, direction, and magnitude of the greatest wind speed observed for each flight. The numbers refer to the dates as listed in Table 4.

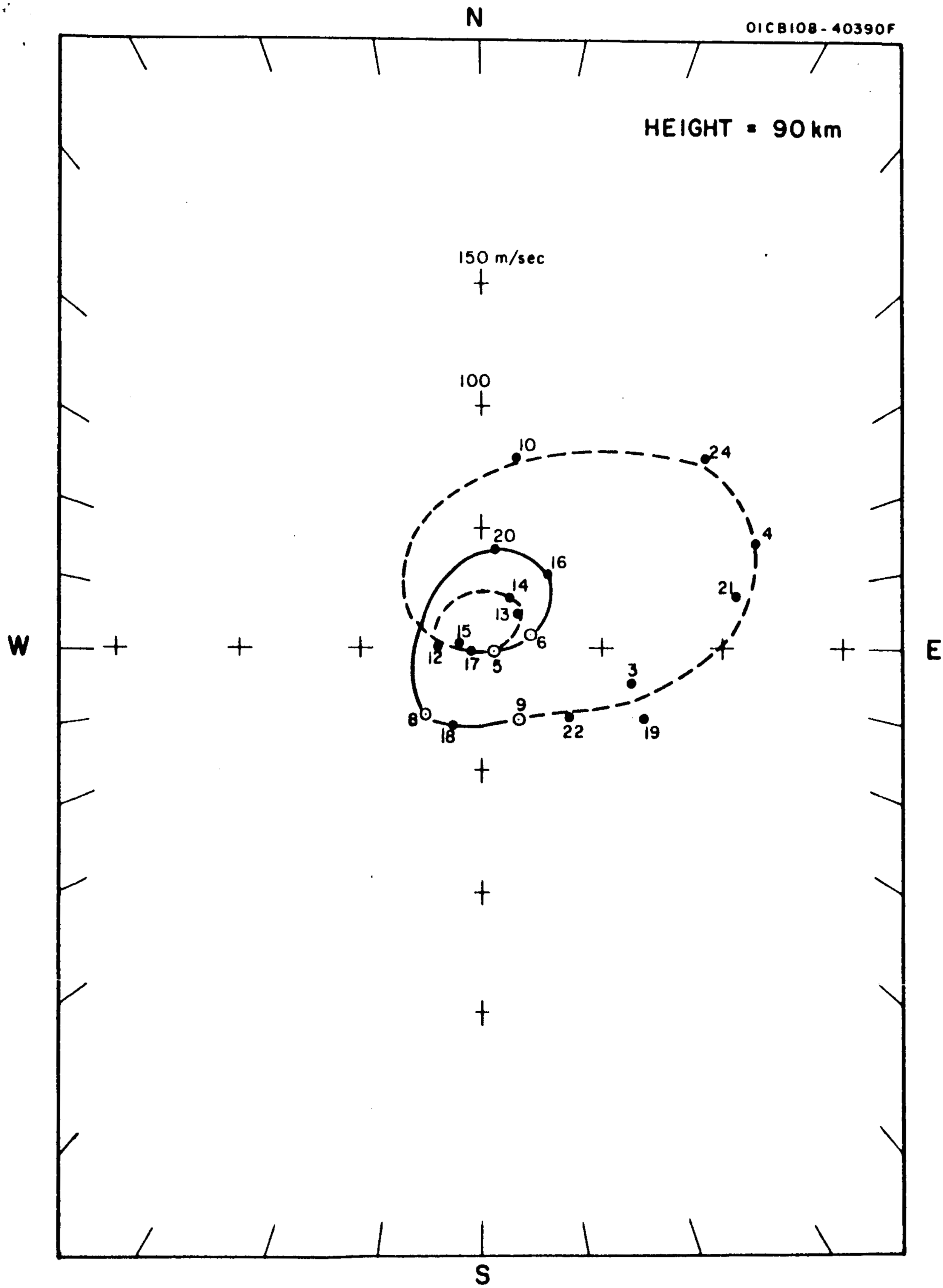

Figure 25. A possible wind periodic pattern for a height of 90 km. The numbers refer to the dates as listed in Table 4.

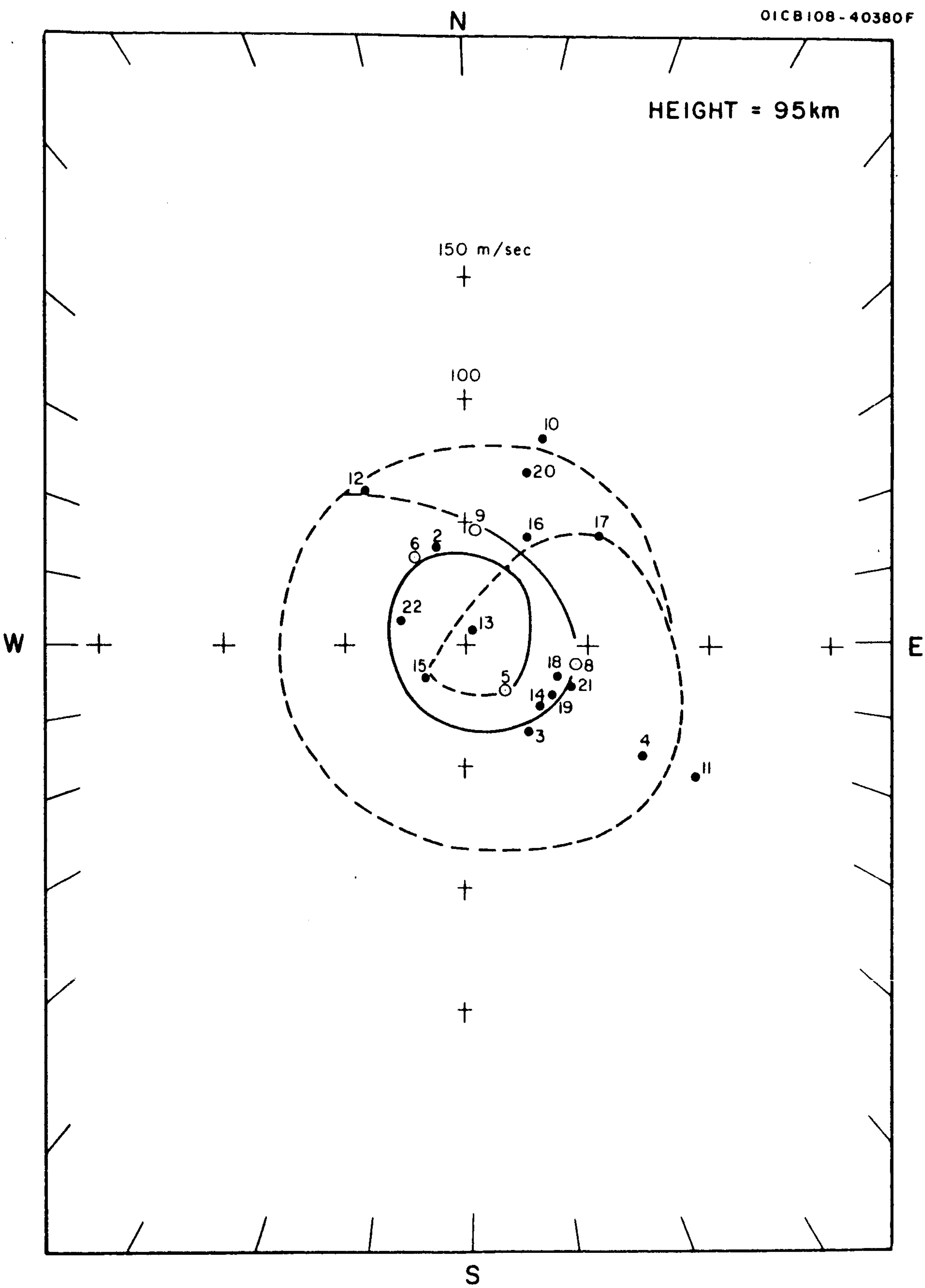

Figure 26. A possible periodic wind pattern for a height of 95 km. The numbers refer to the dates as listed in Table 4.

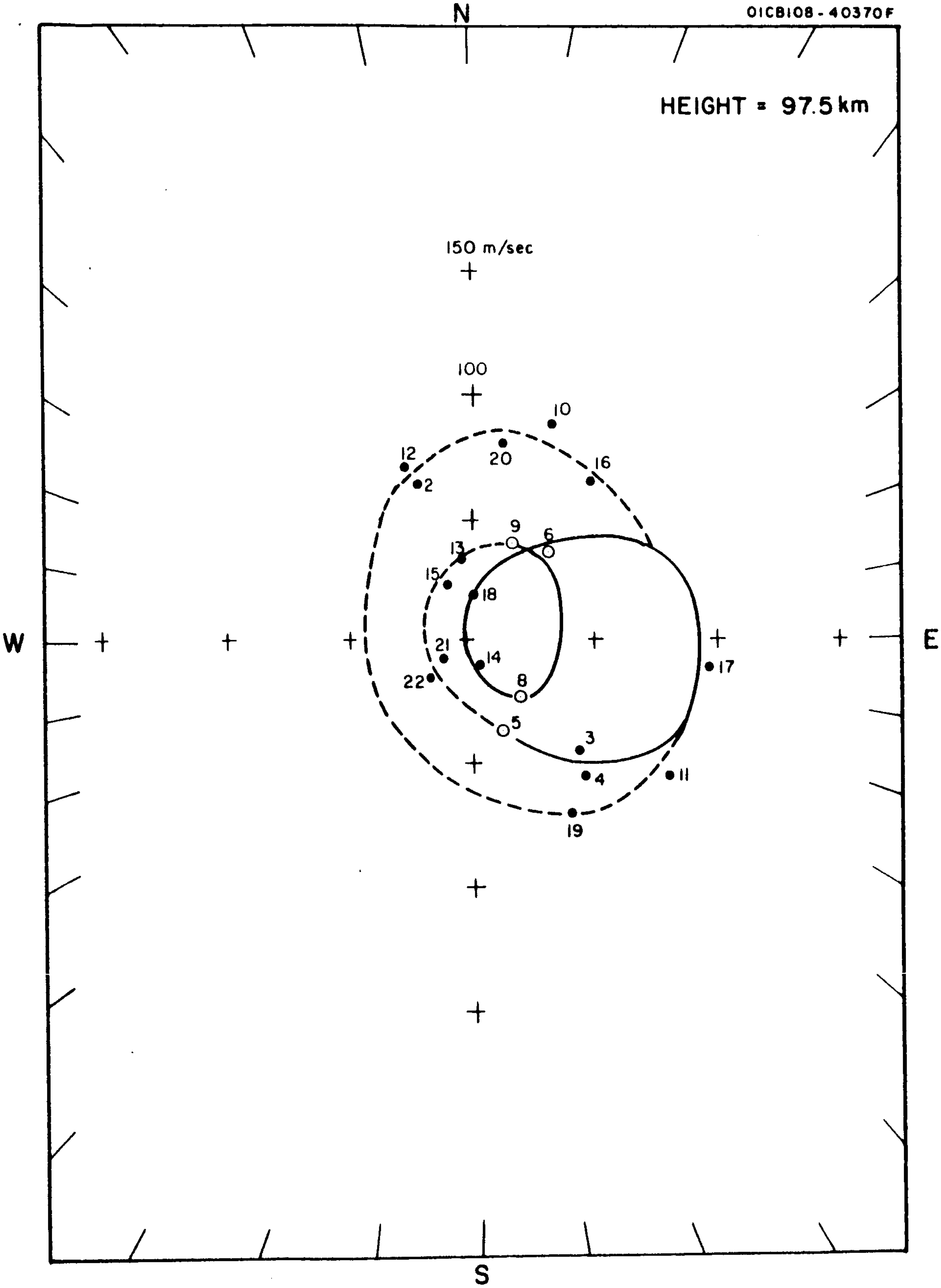

Figure 27. A possible periodic wind pattern for a height of 97.5 km. The numbers refer to the dates as listed in Table 4.

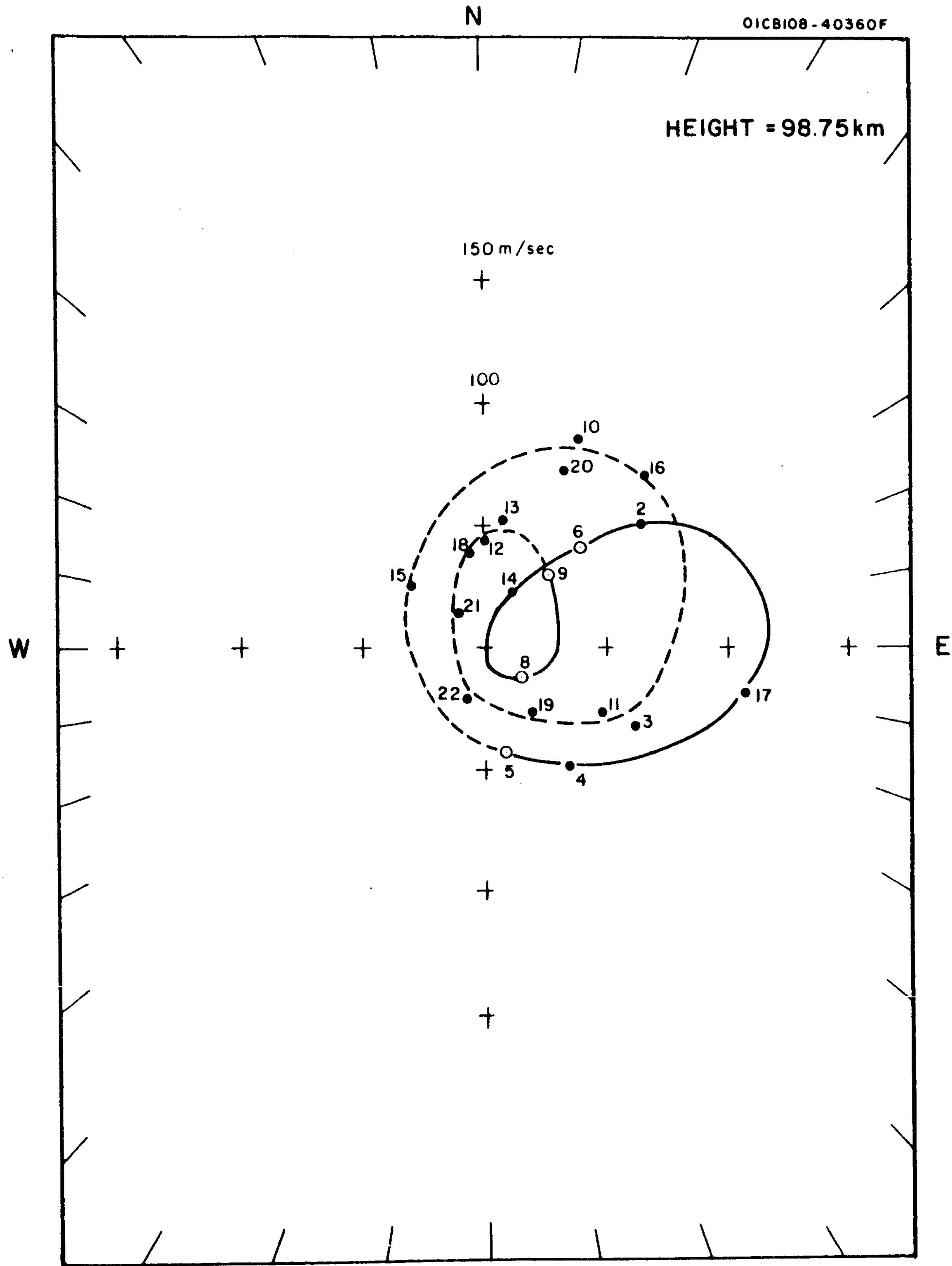

Figure 28. A possible periodic wind pattern for a height of 98.75 km. The numbers refer to the dates as listed in Table 4.

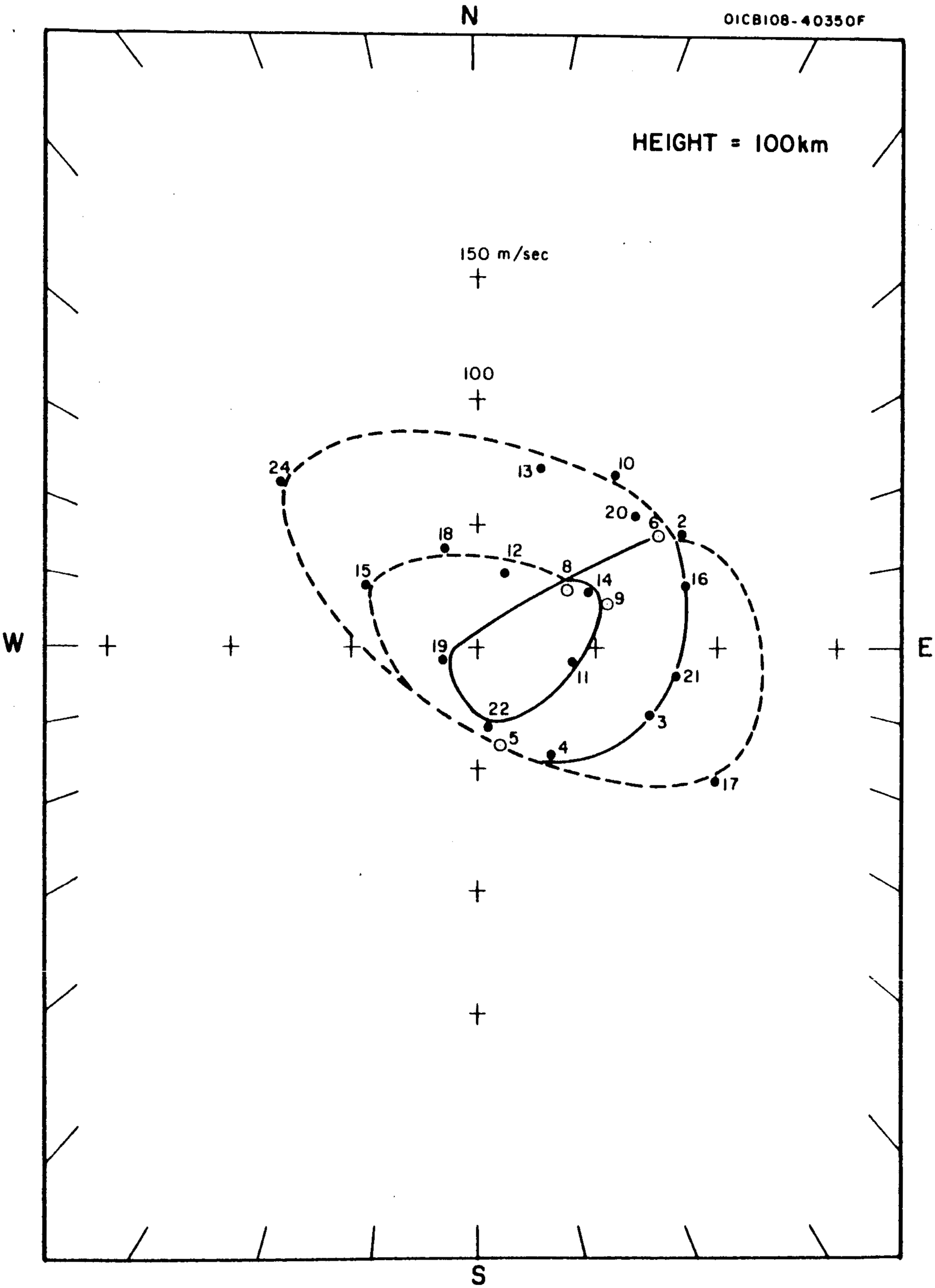

Figure 29. A possible periodic wind pattern for a height of 100 km. The numbers refer to the dates as listed in Table 4.

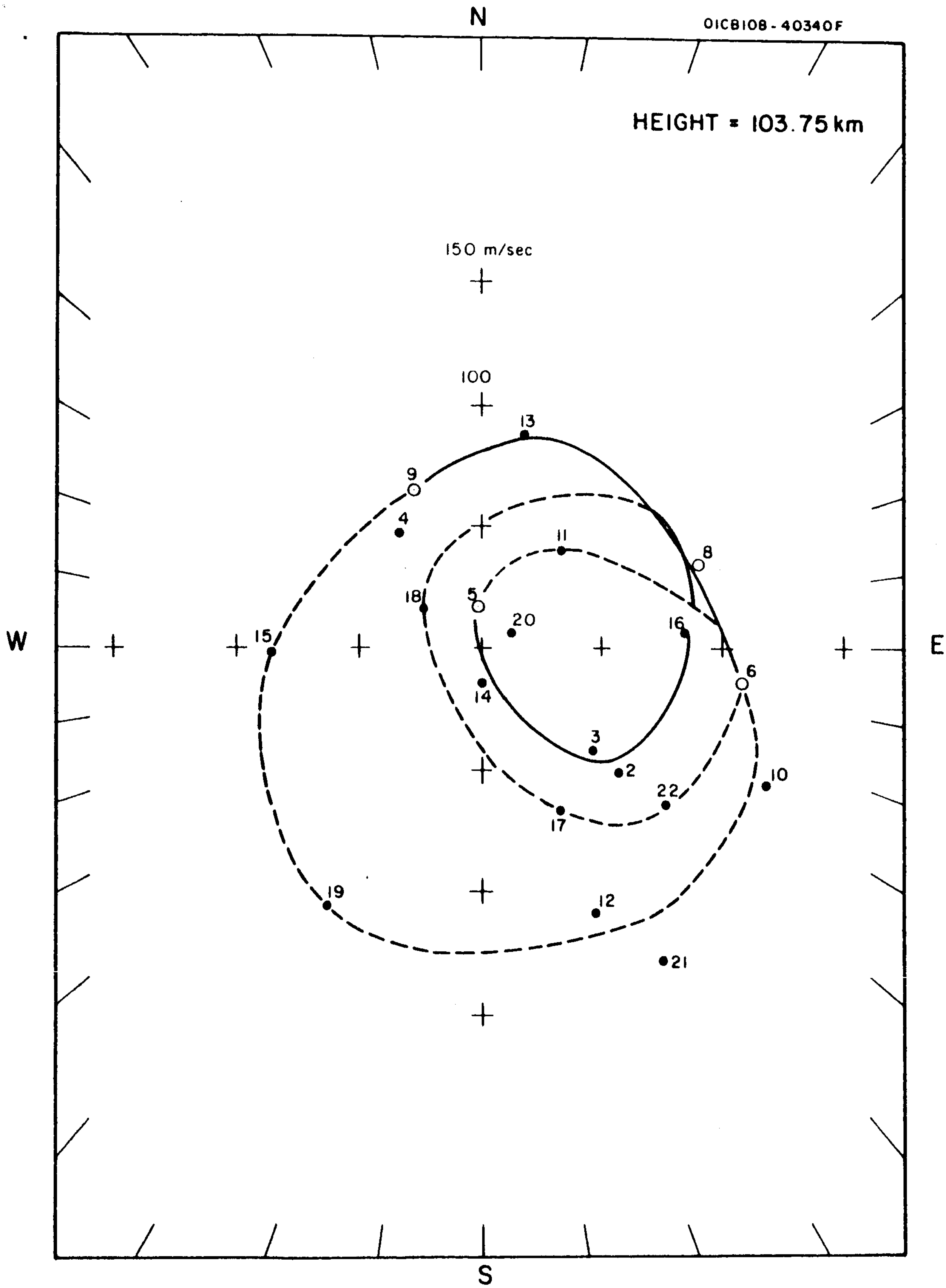

Figure 30. A possible periodic wind pattern for a height of 103.75 km. The numbers refer to the dates as listed in Table 4.

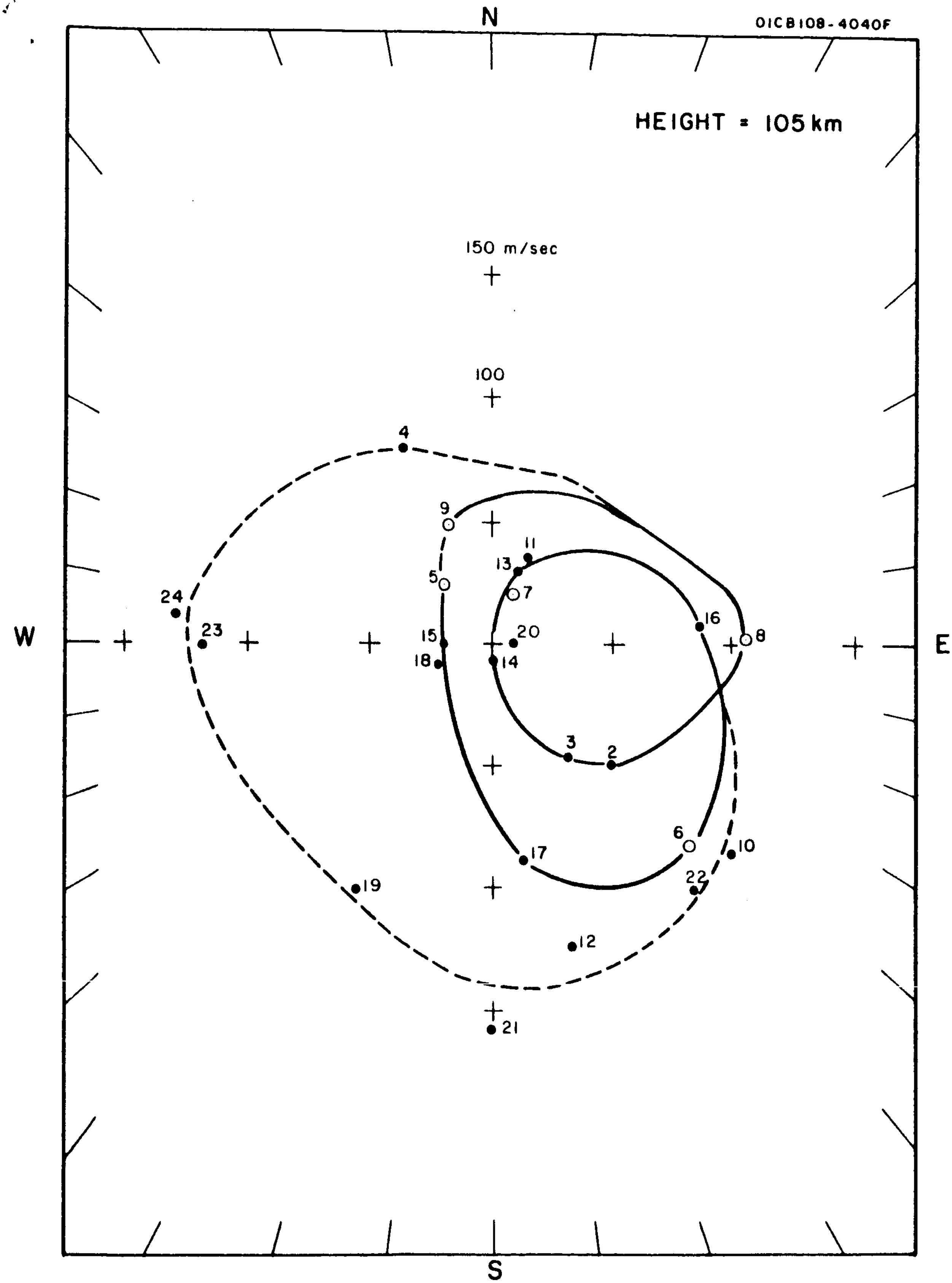

Figure 31. A possible periodic wind pattern for a height of 105 km. The numbers refer to the dates as listed in Table 4.

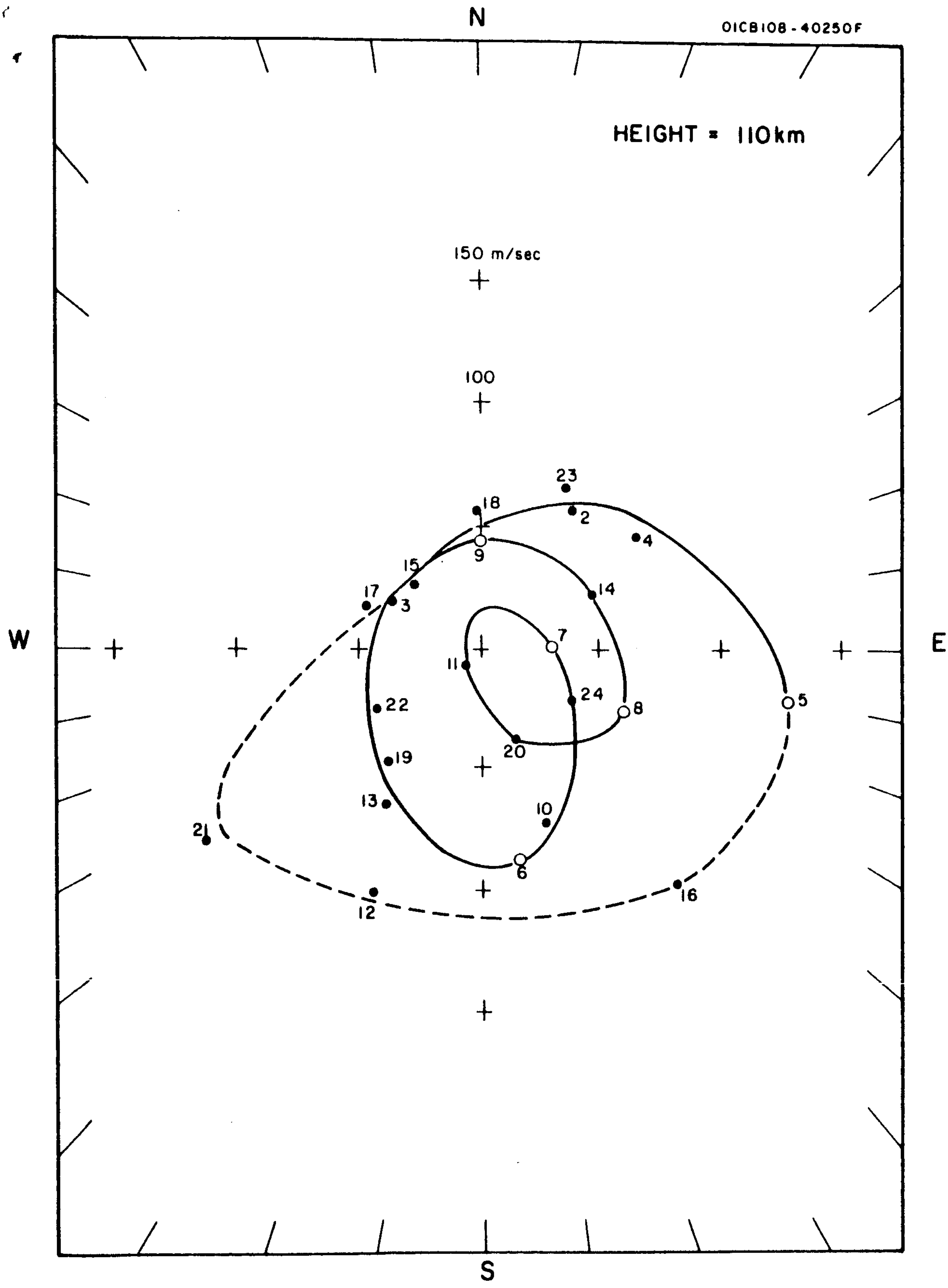

Figure 32. A possible periodic wind pattern for a height of 110 km. The numbers refer to the dates as listed in Table 4.

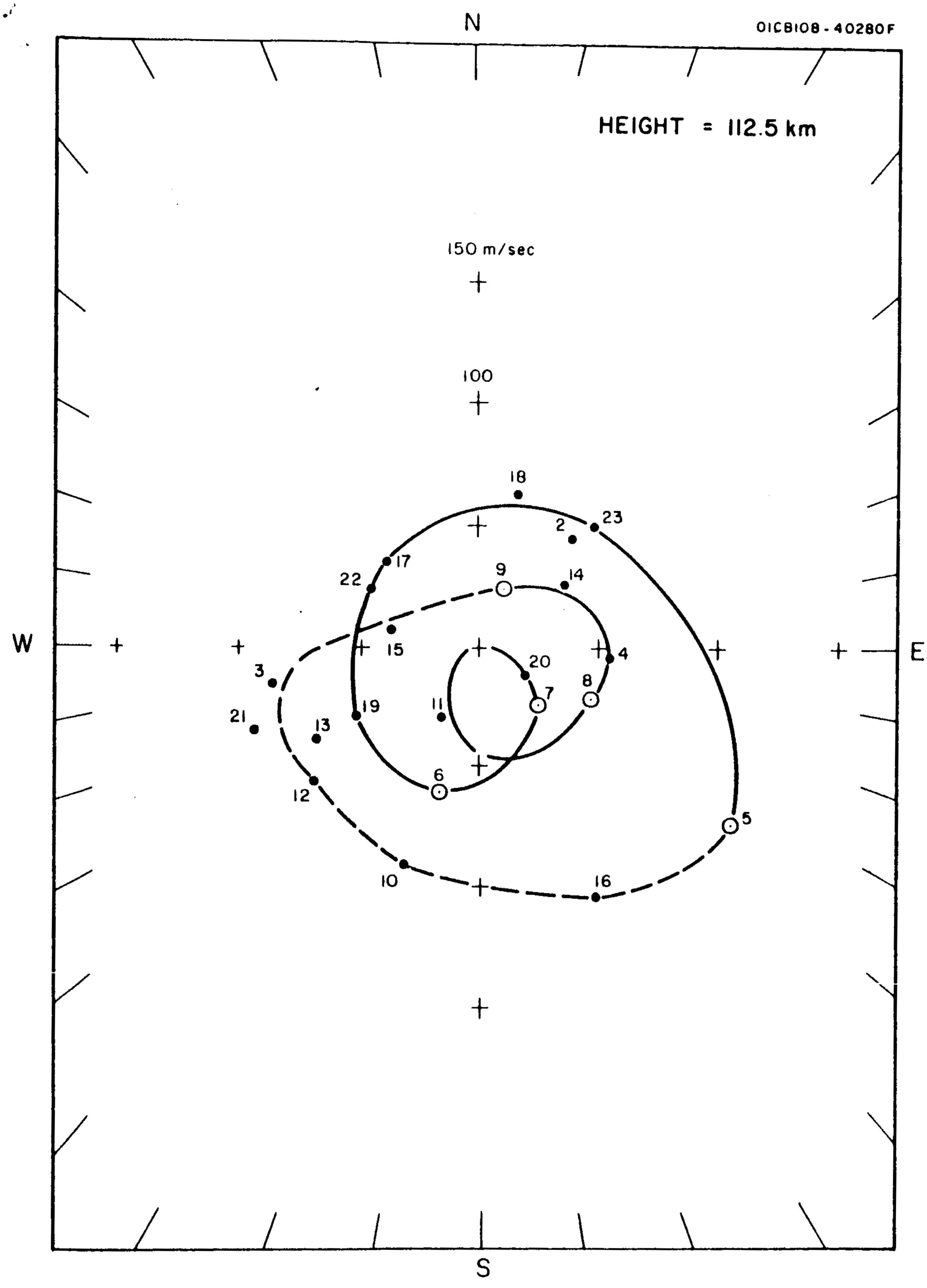

Figure 33. A possible periodic wind pattern for a height of 112.5 km. The numbers refer to the dates as listed in Table 4.

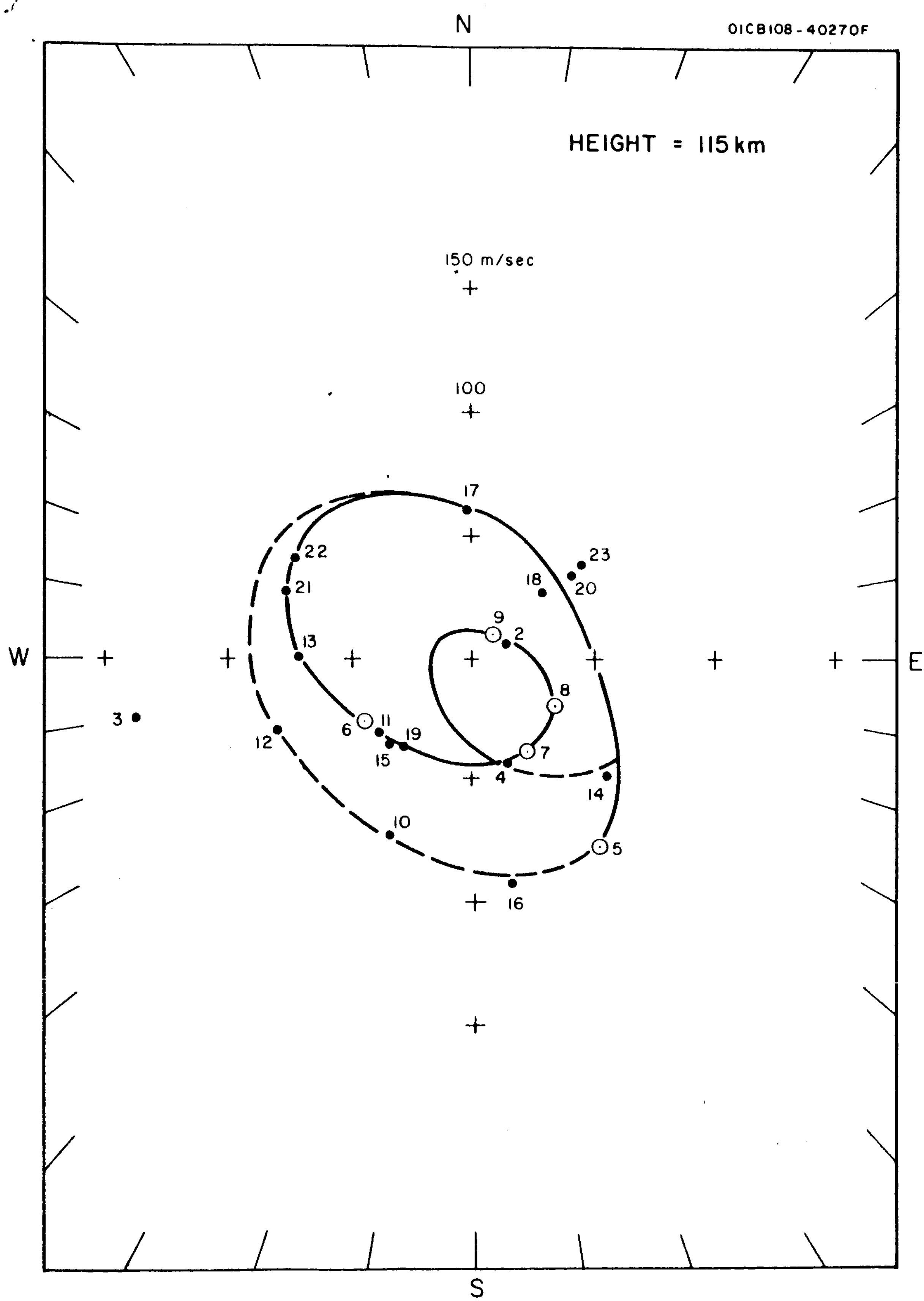

Figure 34. A possible periodic wind pattern for a height of 115 km. The numbers refer to the dates as listed in Table 4.

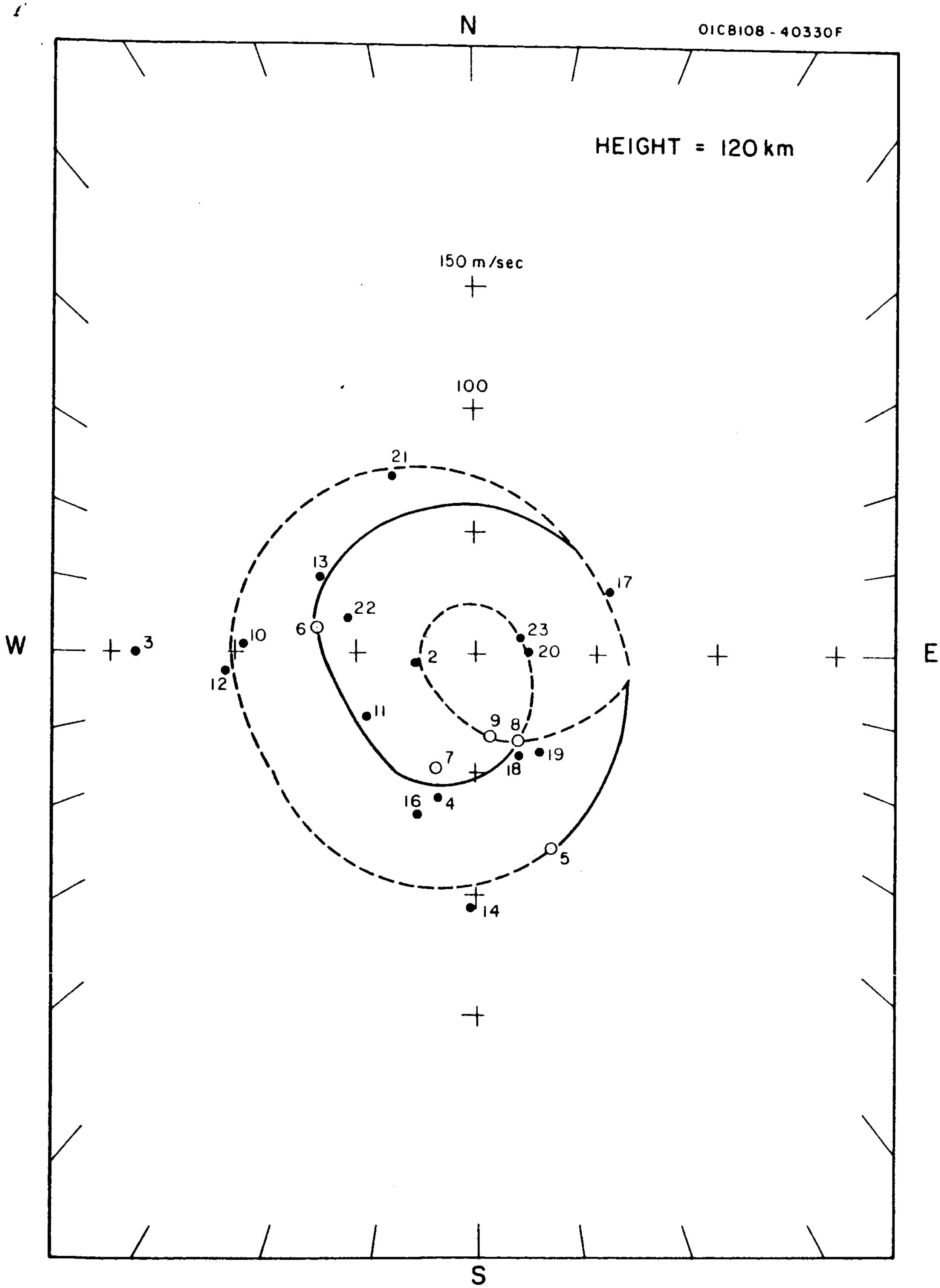

Figure 35. A possible periodic wind pattern for a height of 120 km. The numbers refer to the dates as listed in Table 4.

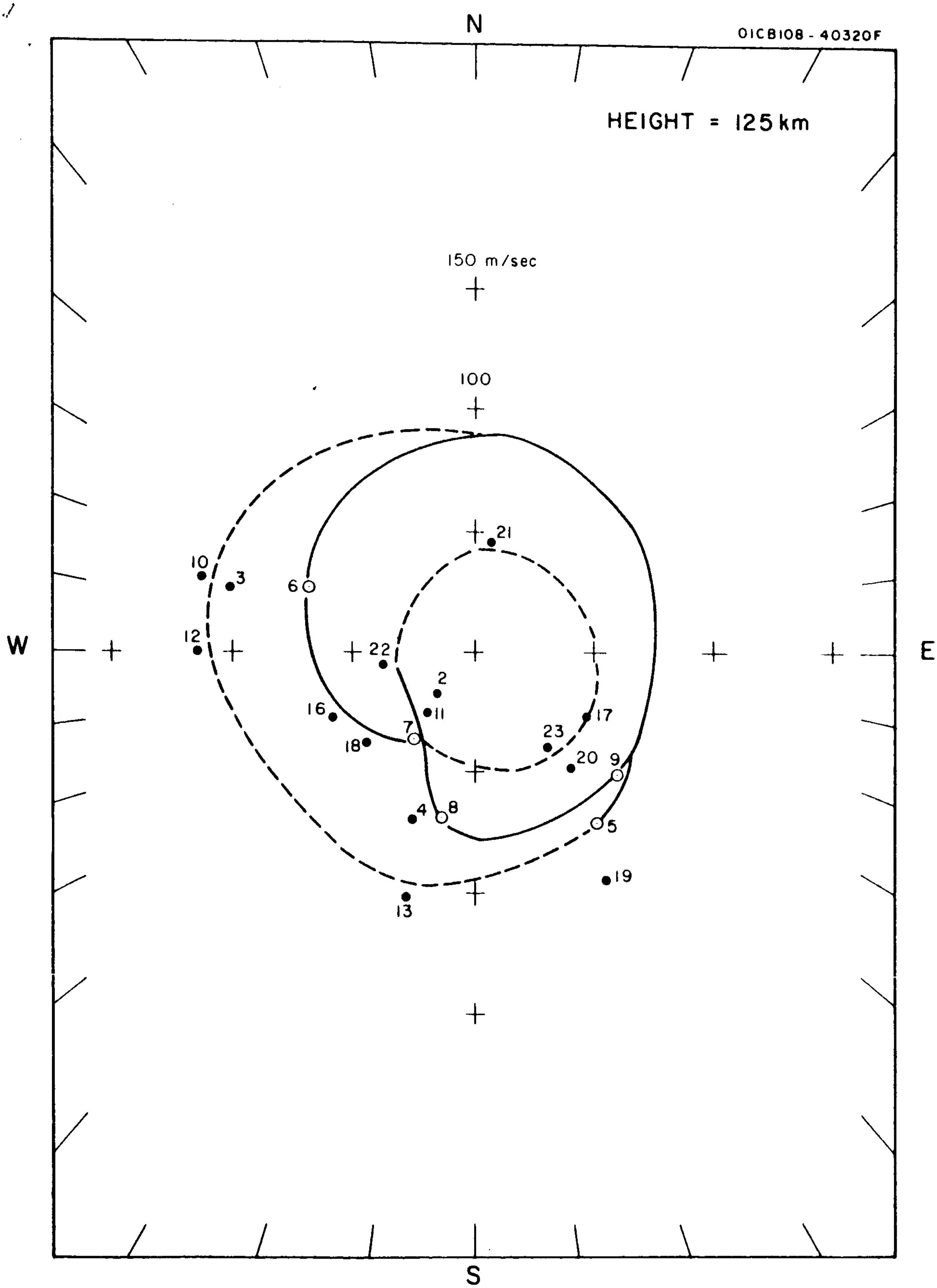

Figure 36. A possible periodic wind pattern for a height of 125 km.
The numbers refer to the dates as listed in Table 4.

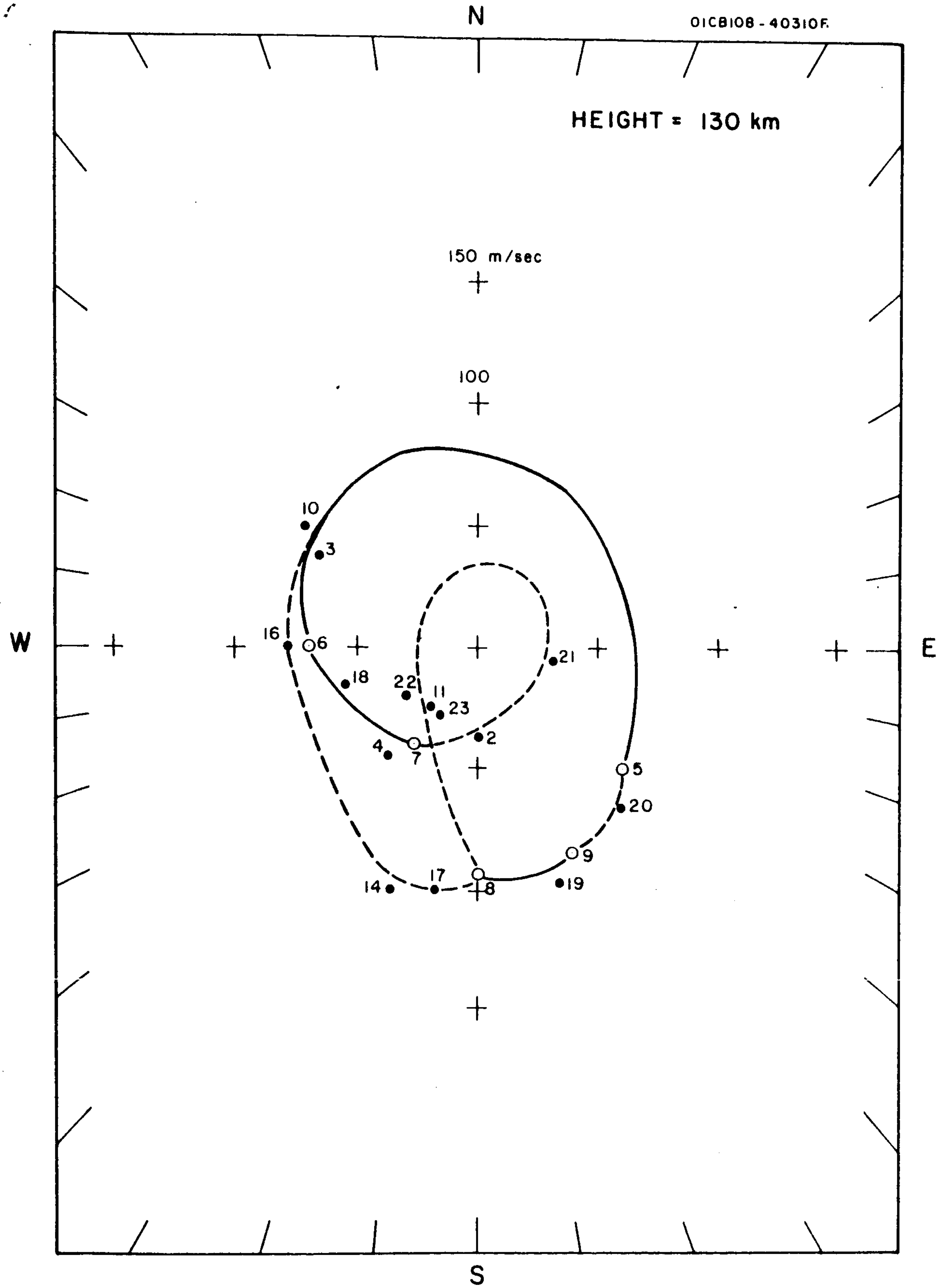

Figure 37. A possible periodic wind pattern for a height of 130 km. The numbers refer to the dates as listed in Table 4.

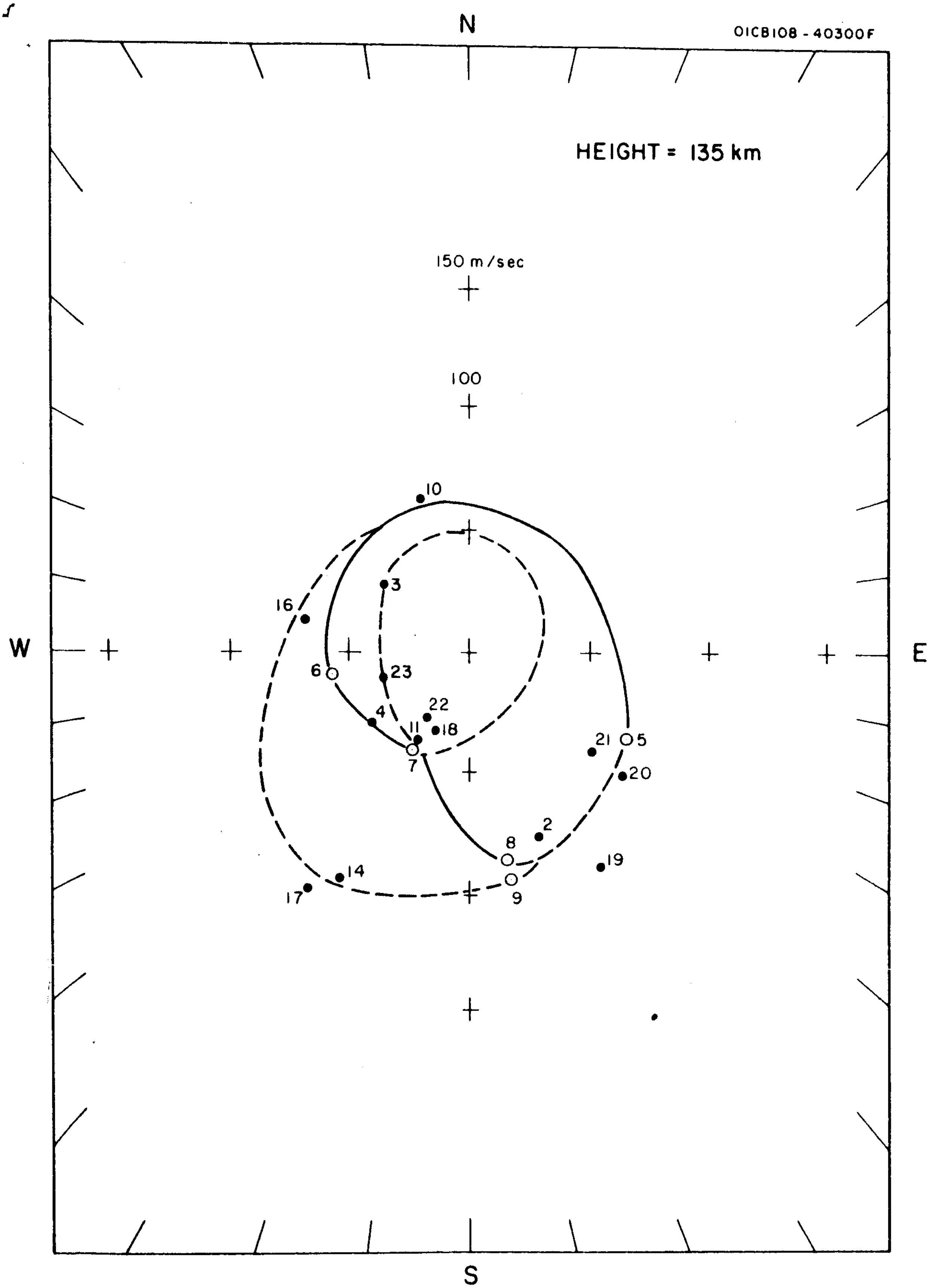

Figure 38. A possible periodic wind pattern for a height of 135 km. The numbers refer to the dates as listed in Table 4.

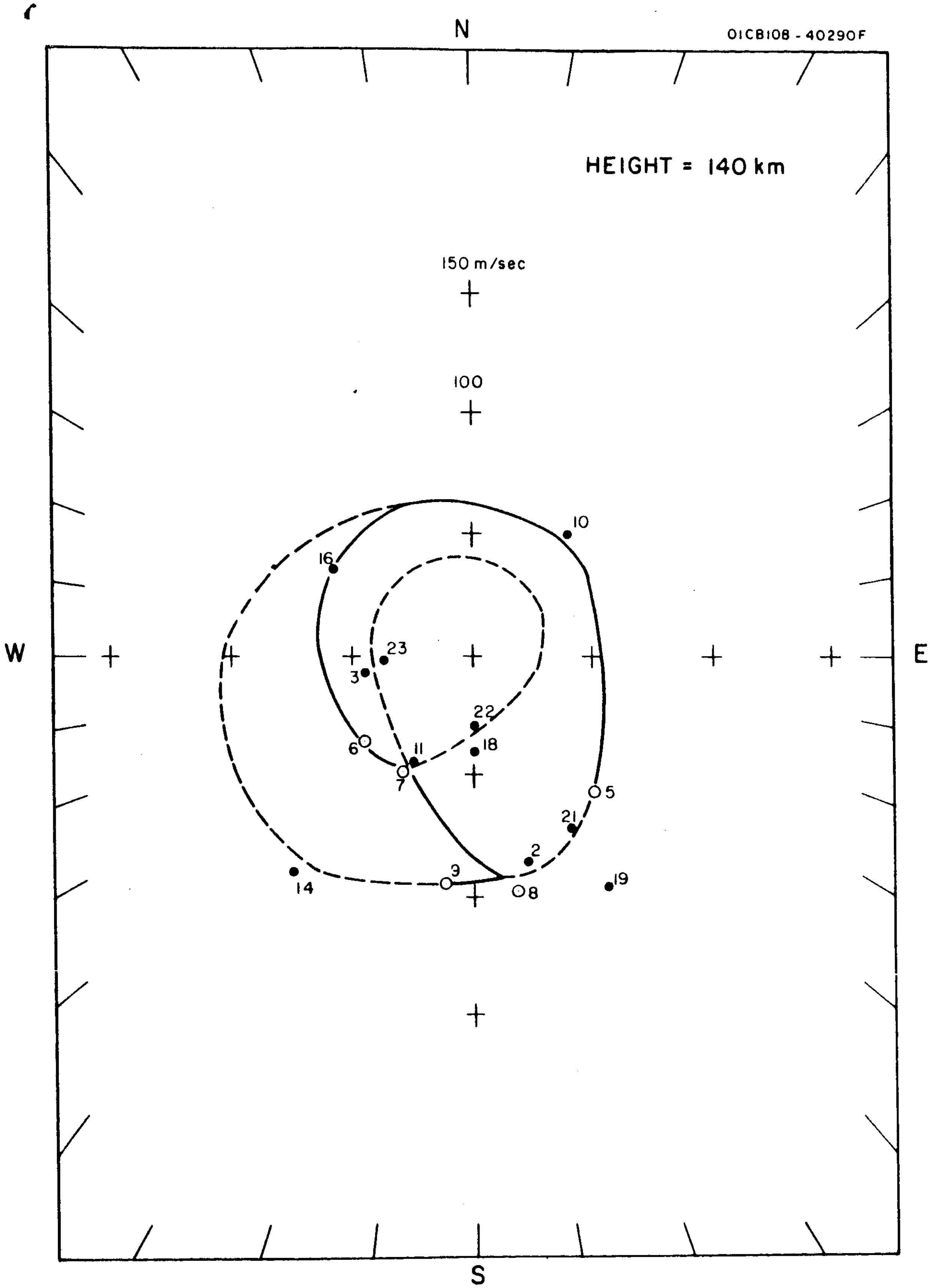

Figure 39. A possible periodic wind pattern for a height of 140 km. The numbers refer to the dates as listed in Table 4.

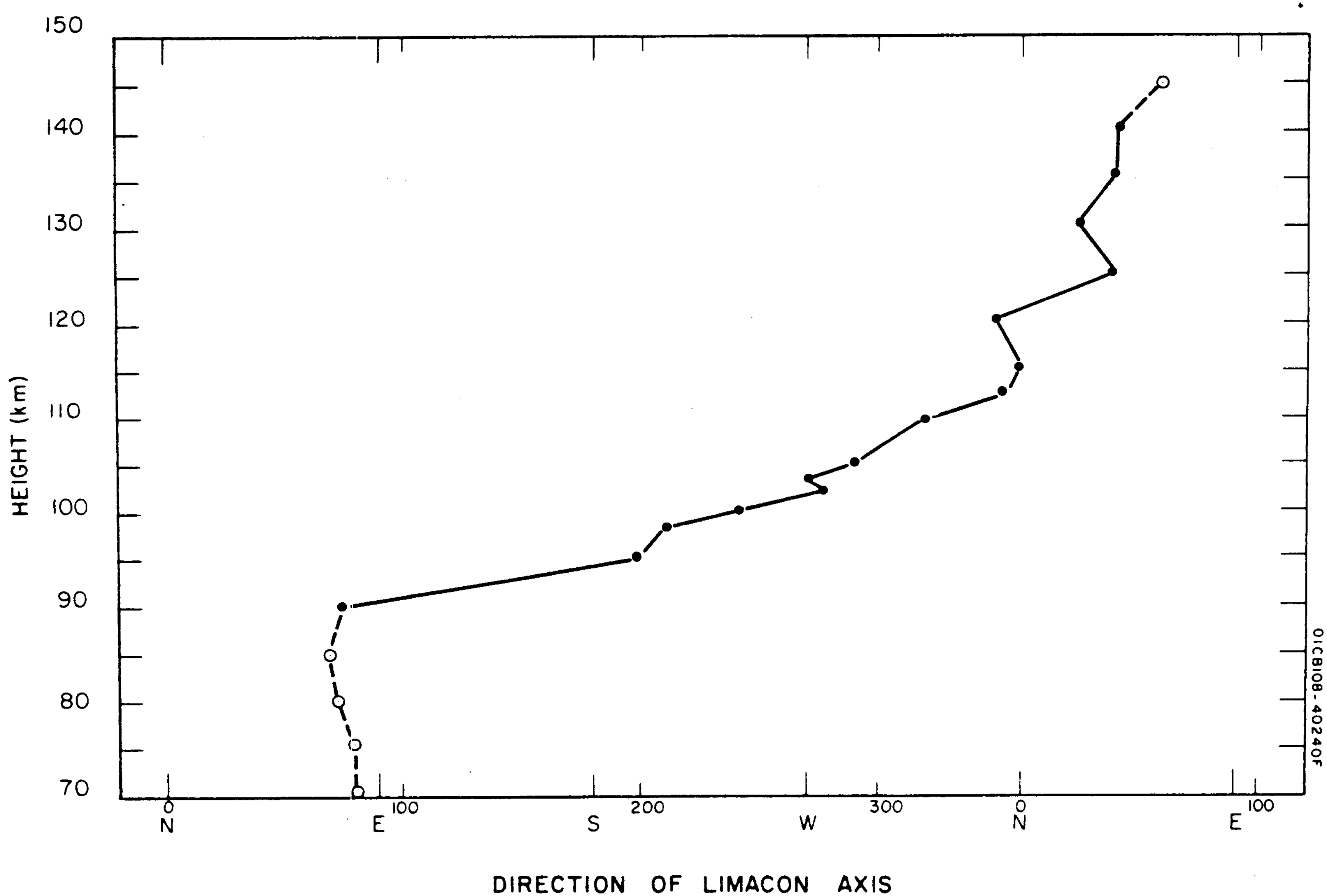

Figure 40. Change of direction of the limacon axis with height.